Title
Nature as nurture: Restorative natural environments and maternal and perinatal health

Author
Gailey, Samantha

Publication Date
2021

UNIVERSITY OF CALIFORNIA,
IRVINE

Nature as Nurture: Restorative Natural Environments and Maternal and Perinatal Health

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Social Ecology

by

Samantha Gailey

Dissertation Committee:

Professor Tim A. Bruckner, Chair

Professor John R. Hipp

Professor Terry Hartig

2021

DEDICATION

To

my mom, my best and oldest friend

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Thank you first and foremost to my advisor and mentor, Dr. Tim A. Bruckner, whose dedication to his students' success is unrivaled (everything else is in E-Prime, I promise).

Thank you to my committee members Dr. John R. Hipp and Dr. Terry Hartig,
as well as Dr. Daniel Stokols, Dr. Paul Piff, and the late Dr. Jenn Kane,
whose guidance, support, and feedback proved invaluable;
to Parvati Singh and Abhery Das, who by now could write their own dissertations on this topic;
to Olivia Humphrey and Stephanie Mohl, without whom these years would have been a lot less fun;
and, above all else, to my parents and partner, Joe Darda, whose love saw me through.

VITA

Samantha Gailey

Education

University of California, Irvine (UCI) Irvine, CA
PhD, Social Ecology 2021
Committee: Tim A. Bruckner (chair), John R. Hipp, Terry Hartig

Gettysburg College Gettysburg, PA
BA with Highest Honors in Psychology and Business 2015
Honors: *summa cum laude,* Phi Beta Kappa

Peer-Reviewed Publications

Gailey, S., Cross, R.I., Messer, L.C., & Bruckner, T.A. (2021). Characteristics associated with downward residential mobility among birthing persons in California. *Social Science & Medicine*. https://doi.org/10.1016/j.socscimed.2021.113962

Bruckner, T.A., **Gailey, S**., Das, A., Gemmill, A., Casey, J.A., Catalano, R., & Shaw, G.M. (*in press*). Stillbirth as left truncation for early neonatal death in California, 1989-2015: A time-series study. *BMC Pregnancy & Childbirth.*

Gailey, S., Bruckner, T.A., Lin, T.K., Liu, J.X., & Herbst, C. (2021). A needs-based methodology to project physicians and nurses to 2030: The case of the Kingdom of Saudi Arabia. *Human Resources for Health, 19*(55). https://rdcu.be/cjwIJ

Gailey, S., McElroy, S., Benmarhnia, T., & Bruckner, T.A. (2021). Green mobility and obesity: A longitudinal analysis of neighborhood greenness in California. *Health & Place, 68* (102503). https://authors.elsevier.com/a/1cSS84pqpjmty3

Gailey, S., & Bruckner, T. A. (2019). Obesity among Black women in food deserts: An "omnibus" test of differential risk. *Social Science and Medicine-Population Health, 7*(100363). https://doi.org/10.1016/j.ssmph.2019.100363

Bruckner, T.A., Buher-Kane, J., **Gailey, S.** (2019). Strong upward neighborhood mobility and preterm birth: A matched-sibling design approach. *Annals of Epidemiology, 36*(5), 48-54. https://doi.org/10.1016/j.annepidem.2019.05.005

Bruckner, T. A., **Gailey, S**., Hallman, S., Amorevieta-Gentil, M., Dillon, L., & Gagnon, A. (2018). Epidemic cycles and environmental pressure in colonial Quebec. *American Journal of Human Biology, 30*(5), e23155. https://doi.org/10.1002/ajhb.23155

Manuscripts Under Review

Gailey, S., Knudsen, E.S, Mortensen, L.H, & Bruckner, T.A. Birth outcomes following unexpected job loss: A matched sibling design. *International Journal of Epidemiology*. Revise & resubmit.

Gailey, S., NCube, C., & Bruckner, T. A. Residential mobility and preterm birth among non-Hispanic Black women in California. Under review.

Book Chapters

Gailey, S., & Bruckner, T. (*forthcoming*). A needs-based approach to projecting physicians and nurses required in the Kingdom of Saudi Arabia." In *World Bank Report*. Washington, DC: International Monetary Fund.

Summary of Expertise

Graduate Student Researcher
More than five years of experience at UCI performing data management, synthesis, and analysis of large state- and national-level health datasets and writing manuscripts for publication. I am fluent in SAS and geographic information systems (GIS) platforms.

Consultant to The World Bank
Quantitative data analyst using epidemiologic models to project the healthcare workforce required to treat the needs of the Kingdom of Saudi Arabia to 2030; co-wrote reports for publication.

Conference Proceedings

Population Association of America
Virtual — May 2021
Conference presentation
"Birth outcomes following unexpected job loss: A matched sibling design"

Population Association of America
Virtual — May 2021
Conference poster
"Green mobility and obesity risk: A longitudinal analysis in California

Society for Epidemiologic Research
Virtual — Dec 2020
Conference poster
"Strong upward residential mobility and preterm birth: A sibling control design in California"

American Psychological Association
Chicago, Illinois — Aug 2019
Conference presentation
"Are nature lovers happier and healthier? Examining relations among nature connectedness, positive affect, and general health"

Interdisciplinary Association for Population Health Science
Seattle, Washington — Oct 2019
Conference poster
"Greenspace and obesity risk among non-Hispanic black and white women"

Population Association of America
Austin, Texas Apr 2019
Conference presentation
"Maternal cumulative exposure to adverse neighborhood environments and preterm birth"

Population Association of America
Denver, Colorado Apr 2018
Conference poster
"Obesity and the neighborhood food environment: Intersections of race and poverty"

Program of Research in Demographic History
Montreal QC, Canada Nov 2017
Conference presentation
"Epidemic cycles and environmental pressure in colonial Quebec"

Awards, Honors & Grants

- Social Ecology Excellence in Research Award, Department of Social Ecology, UCI, 2021
- "Health disparity or survival advantage: The case of non-Hispanic black preterm birth," Seed Funding (Graduate Student Researcher), Center for Population, Inequality, and Policy, UCI, 2020
- "Preconception neighborhood environments and poor infant health: A quasi-experimental analysis," Small Research Grant (Graduate Student Researcher), Center for Demographic and Social Analysis, UCI, 2018
- Graduate Student Mentoring & Teaching Award, UCI, 2016-2017
- Phi Beta Kappa, Gettysburg College, 2015
- James Boyd Hartzell Memorial Award (Annual Award for Outstanding Scholarship), Gettysburg College, 2015
- Presidential Scholar (Highest Merit Scholarship for Entering Students), Gettysburg College, 2011-2015

Teaching Experience

Graduate Teaching Assistant
Responsibilities include leading weekly discussion sections and bi-quarterly exam review sessions, holding office hours, managing course websites, creating exam questions, and grading coursework.

Courses: Research Design (Fall '15), Environmental Psychology (Winter '16), Positive Psychology (Spring '16), Human Stress (Fall '16, Spring '17), Naturalistic Field Research (Winter '17, Spring '18, Spring '19), Abnormal Psychology (Fall '17, Fall '18), Developmental Psychopathology (Winter '19), Attachment Relationships (Fall '19), Psychology Fundamentals (Winter '20), Foundations of Community Health (Spring '20), Principles of Public Health (Fall '20)

Guest Lectures

Foundations of Community Health, Program in Public Health, UCI (Spring 2020)
Lecture: "Neighborhoods and Health," class size approx. 150
Foundations of Community Health, Program in Public Health, UCI (Spring 2020)
Lecture: "Zoning and Environmental Justice," class size approx. 150
Ecology of Healthy Communities, School of Nursing, UCI (Fall 2019)
Lecture: "Environmental Impacts on Health," class size approx. 10
Environmental Psychology, School of Social Ecology, UCI (Winter 2016)
Lecture: "Restorative Natural Environments," class size approx. 300

Refereeing

- *Journal of Racial and Ethnic Health Disparities*
- *Applied Research in Quality of Life*
- *Ecopsychology*
- American Psychological Association (APA), Division 34 (Society for Environmental, Population, and Conservation Psychology)

Professional Memberships

- Population Association of America (PAA)
- American Psychological Association (APA)
- Interdisciplinary Association for Population Health Science (IAPHS)
- Society for Epidemiologic Research (SER)

ABSTRACT OF THE DISSERTATION

Nature as Nurture: Restorative Natural Environments and Maternal and Perinatal Health

by

Samantha Gailey

Doctor of Philosophy in Social Ecology

University of California, Irvine, 2021

Professor Tim A. Bruckner, Chair

Background: Experimental and observational evidence in the fields of psychology, epidemiology, and urban planning supports a protective association between residential greenspace and health. Population research, however, relies primarily on cross-sectional data, which cannot rule out the rival hypothesis of 'residential selection,' in which healthier or socioeconomically advantaged individuals, over time, move to neighborhoods with greater greenspace. Moreover, few studies assess heterogeneity in relations between greenspace and health by sociodemographic characteristics, including race/ethnicity. These limitations leave open the questions of whether and for whom residential greenspace matters.

Objective: This program of research advances the literature by (i.) using unique, longitudinal datasets to test whether changes in residential greenspace, or 'green mobility,' precede perinatal health improvements, (ii.) examining whether health benefits differ by maternal race/ethnicity, and (iii.) assessing the extent of bias induced by residential selection, a key, and often overlooked, threat to validity in research on greenspace and health.

Methods: I used a probabilistic record linkage algorithm to identify births to the same mother in California between 2005 and 2015 and defined green mobility as census tract-level changes in the

Normalized Difference Vegetation Index (NDVI), derived from satellite images of the earth's surface, between births. Chapter 2 leverages a sibling comparison design to examine whether green mobility precedes reductions in maternal obesity risk, adjusting for obesity status at baseline. Chapter 3 uses maternal fixed effects analyses to assess whether green mobility varies with higher birthweight and lower risk of preterm birth (PTB) among non-Hispanic (NH) white and NH Black mothers, controlling for unmeasured maternal confounders involved in residential selection. Chapter 4 explores socioeconomic and health characteristics associated with subsequent green mobility, and whether patterns of social and health selection differ for NH white and NH Black mothers.

Results: Findings indicate that upward green mobility varies with reduced obesity risk (Chapter 2) and increased birthweight in NH Black but not NH white mothers (Chapter 3). Results of Chapter 4 suggest that residential selection does not heavily confound previously observed findings but indicate important differences in patterns of residential selection for NH white and NH Black mothers.

Conclusions: Taken together, findings from this program of research suggest, consistent with prior theoretical, experimental, and cross-sectional work, that increases in residential greenspace precede improvements in maternal and perinatal health. NH Black mothers, in particular, appear to benefit from increases in neighborhood greenness. The role of greenspace appears less certain for NH white mothers, who may selectively move to greener neighborhoods based on factors that also correlate with better health. Urban greening projects that target NH Black communities — but avoid the paradoxical effects of 'green gentrification' — may reduce persistent disparities in perinatal health.

CHAPTER 1

Introduction

In 2016, the journal *Science* released a special issue ('Urban Planet') focused on the dramatic transformation of natural and built environments in an age of global urbanization (Wigginton et al., 2016). In 1960, urban populations accounted for a third of the total global population. Today, more than half of the world's people live in cities (UN World Urbanization Prospects, 2018). Along with widespread industrialization and environmental degradation, the rise of cities brings much of the global population closer to crowding, noise, air pollutants, crime, and other urban exposures that degrade mental and physical health (Hartig & Kahn, 2016; Peen et al., 1996).

As the urban population continues to grow, Hartig and Kahn (2016) highlight the necessity of taking advantage of opportunities to integrate natural features into the design of rising cities. Incorporating nature into urban designs (e.g., urban parks, street tree canopies, community gardens, green roofs, walking trails, etc.) may protect urban populations against the risks of urban life (Hartig & Kahn, 2016). Supporting their position, accumulating research over the past three decades suggests that nature confers widespread physical and psychological benefits to health (Bowler et al., 2010; Hartig et al., 2014; Kondo et al., 2018). Extensive evidence from experimental research in laboratory and natural settings, for instance, shows that even brief experiences with nature can promote restoration from conditions of cognitive fatigue and stress that prevail in urban life (Bowler et al., 2010; Hartig & Kahn, 2016; Kondo et al., 2018; McMahan & Estes, 2015).

Individual-level findings of nature's restorative effects inform a growing body of population-level research on associations between neighborhood greenspace and health (Hartig et al., 2014). Epidemiologic research finds that access to greenspace correlates with greater general health (e.g. Dadvand et al., 2016; de Vries et al., 2003; Triguero-Mas et al., 2015) and with reduced risk for myriad physical and psychiatric morbidities, including cardiovascular disease, adverse birth outcomes, obesity, and depression (Hartig et al., 2014; James et al., 2015; Maas et al., 2009; Pereira et al., 2012; 2013).

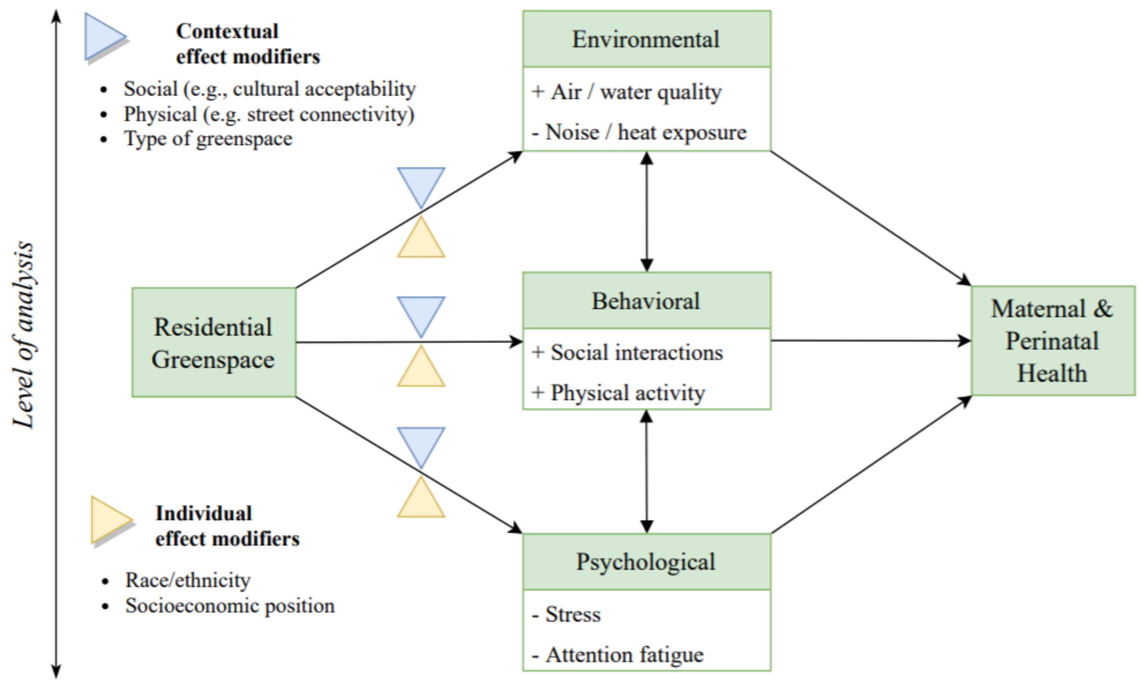
Individual- and population-level studies support protective associations between natural environments and mental and physical health. As the urban population grows in an increasingly 'urban world,' understanding the benefits of nature to human health serves a crucial function in advancing efforts to preserve and incorporate nature into urban designs (Hartig & Kahn, 2016). Few population studies, however, employ designs from which we can infer causality, or assess for whom nature matters most. Due in part to these limitations, health promotion interventions lack specificity in terms of targeting specific health outcomes or populations that may benefit from urban greenspaces.

As natural resources and opportunities for experiences in nature grow scarce, the goals for future research must shift away from documenting widespread correlations. Research that seeks to understand *causal* relations between greenspaces and health, and *whom* these spaces serve, can inform urban planning and environmental health policy. To this end, my program of research aims to: (1) contribute population-level evidence to estimate causal relations between neighborhood greenspace and health, including obesity and birth outcomes; (2) explore heterogeneity in associations between greenspace and health, with a focus on vulnerable populations; and (3) identify and examine threats to validity in population-level research, including, most notably, residential selection.

Literature Review

In this section I review current evidence of pathways and associations between nature and health. I divide my literature review into three areas, each of which focuses on a different aspect of nature as it relates to health: (1) Nature as a Restorative Experience, (2) Nature as a Behavior Setting, and (3) Nature as a Physical Environment (Hartig et al., 2014). Given that nature can simultaneously function as an experience, a behavior setting, and a physical environment, it remains possible (and perhaps likely) that pathways operate interactively to influence health (Hartig et al., 2014; Markevych et al., 2017). Figure 1.1 illustrates these pathways:

Figure 1.1. Potential pathways and effect-modifiers underlying greenspace/health relations.



Nature as a Restorative Experience

Ulrich et al. (1991) characterize several broad perspectives on person-environment interactions. Different perspectives converge to predict that experiences with nature will promote restoration among individuals under conditions of stress or attentional fatigue. Conceptual perspectives diverge, however, in their definitions of 'restorative environments,' including the types of natural features or settings that elicit psychological and physiological restoration, and the central mechanisms through which contact with nature confers affective, cognitive, and/or physiological benefits.

Cultural and other learning-based perspectives posit that individuals form (or learn) positive associations with natural environments through shared cultural or individual experiences (Ulrich et al., 1991). Cultural perspectives hold that certain communities foster a shared appreciation or reverence for nature, and, conversely, teach members to dislike cities or urban environments (Tuan, 1974). Learning-based perspectives suggest individual differences in responses to nature according to early childhood experiences. Such theories predict that individuals who form positive associations with nature during childhood through pleasurable experiences, such as family vacations to mountains or beaches, will respond more positively to natural features or settings later in life, compared to individuals who lack positive associations with nature (Ulrich et al., 1991).

Arousal theories more broadly contend that settings with low-arousal inducing properties, including (but not limited to) certain types of natural environments, may facilitate more rapid recovery from stress than high-arousal settings (Berlyne, 1971). Overload perspectives, moreover, predict that individuals exposed to environments with high-levels of complexity, intensity, or movement (high-arousal properties) can further tax human information-processing systems and hinder restoration of depleted resources (Cohen, 1978).

The two most prominent theories of restorative environments, stress recovery theory (SRT; Ulrich, 1984), also referred to as psychoevolutionary theory, and attention restoration theory (ART; Kaplan & Kaplan, 1989) derive from an evolutionary-based perspective. This perspective assumes that, because evolution occurred primarily in natural environments, humans possess an innate, or unlearned predisposition to respond in adaptive ways to different types of natural features. For example, exposure to natural settings characterized as 'favorable to pre-modern humans from the standpoint of yielding food and drinking water' will produce a rapid, positive affective response (Ulrich et al., 1984, p. 205). Evidence supporting the underlying assumptions of evolutionary perspectives shows that people prefer specific natural features (e.g. vegetation, tree canopies) characteristic of savanna-like environments which signal the provision of food and water (Orians, 1986).

Cognitively based evolutionary perspectives suggest that neurocognitive systems evolved in and calibrated to natural environments. Urban environments in the modern world, thus, place greater strain on attention-processing resources susceptible to fatigue (e.g. Wohlwill, 1983). ART (Kaplan & Kaplan, 1989) holds that natural environments possess intrinsically interesting, or 'fascinating,' features that engage attention automatically, rather than through directed effort (Kaplan, 1995). ART builds on William James' (1892) early conception of a dual information-processing system comprised of 'voluntary' and 'involuntary' attention. 'Voluntary attention' (James, 1892) or 'directed attention' (Kaplan, 1995) controls distraction through an inhibitory mechanism which becomes depleted through continual use. 'Involuntary attention' (James, 1892) or 'fascination' (Kaplan, 1995) in contrast, requires no effort and does not deplete over time. ART suggests that 'restorative' natural environments, in addition to inspiring fascination (by engaging involuntary attention), must also foster a sense of 'being away,' 'extent,' and 'compatibility' (with an individual's goals) (Kaplan, 1995). According to ART, experiences with restorative environments allow for the neurocognitive mechanism underlying directed attention to replenish and, thus, improve cognitive functioning (Kaplan & Kaplan, 1989; Kaplan, 1995).

Ulrich (1991), however, argues that attention cannot operate as the central mechanism through which contact with nature restores adaptive resources, given evidence (Dimberg, 1986) that individuals also attend automatically to natural stimuli that invoke a sense of danger (e.g., venomous snakes) and promote, rather than restore, psychophysiological stress (Ulrich, 1991). Supporting this argument, Ulrich et al. (1991) finds experimental evidence that both exposure to stressful stimuli and restorative natural environments elicit high levels of sustained attention, suggesting that nature can 'work both ways' in terms of providing opportunities for promoting and reducing stress. In addition, Ulrich et al. (1991) counter ART, arguing that responses to nature operate 'preconsciously' — that is, in the absence of cognitive awareness, processing, or appraisal of specific natural features. Some evidence indicates that subliminal ('preconscious') presentations of natural environments containing danger-invoking stimuli (e.g., snakes) elicit strong autonomic responses in the absence of cognitive appraisals of stress (Orians, 1986).

In his psychoevolutionary framework (or SRT), Ulrich (1984) contends that experiences with restorative environments elicit an automatic affective response, rather than a conscious cognitive response, which, in turn, influences the psychological and physiological processes involved in the stress response. SRT, moreover, holds that responses to nature should operate adaptively, such that they engender appropriate emotional states that motivate approach-avoidance behavior to facilitate ongoing survival (Ulrich, 1984; Ulrich et al., 1991). Whereas exposure to natural environments containing dangerous stimuli induce negatively-toned emotional states, accompanied by avoidance behavior, SRT argues that exposure to non-threatening nature (e.g. savanna-like settings) under conditions of stress portends a shift toward positively-toned emotional states and a reduction in physiological activity (Ulrich, 1984; Ulrich et al., 1991).

ART and SRT forward that encounters with certain natural settings can foster restorative experiences that involve salutary cognitive, affective, and physiological changes. They hold conflicting positions, however, in terms of the key aspects of nature that encourage individuals to seek out and/or benefit from nature exposure (Hartig et al., 2003; Kaplan, 1995). ART posits a central role of directed attention, which, when depleted through prolonged use, can lead to reduced cognitive performance and greater susceptibility to stress. Natural features that capture attention effortless, ART argues, can reduce demand on the fatigued capacity for directed attention, enabling renewal of depleted attentional resources. SRT, in contrast, holds that exposure to survival-oriented natural settings elicits a rapid shift toward positive emotions, which, in turn, attenuates the stress response. SRT, moreover, focuses on the role of nature experiences under conditions of stress, whereas ART contends that nature treats universal cognitive deficits that prevail in modern urban life (Hartig et al., 2003; Kaplan, 1995).

ART and SRT, as well as other conceptual perspectives (e.g., cultural, arousal) on person-environment interactions, propose different causal pathways through which experiences with nature confer psychological and physiological benefits. Restorative environments theories predict similar short-term restorative outcomes (e.g., improvements in cognitive performance, increases in positive affect, reductions in physiological activity) following brief bouts with nature. ART and SRT, however, propose different central mechanisms (attentional vs affective) through which restoration occurs. In addition, ART and SRT focus on the role of different aspects of natural environments in promoting restoration under different antecedent conditions. These theoretical differences may hold implications for population-level research and health promotion interventions on restorative natural environments. In the next section, I discuss evidence of attention restoration and stress reduction pathways in individual- and population-level research.

Experimental Research

An extensive body of experimental research in laboratory and field settings over the past four decades provides evidence of nature's short-term health benefits. Guided by ART and SRT, much work in this area investigates whether and to what extent experiences with nature can lead to improved functioning in psychological and physiological systems. Substantial evidence indicates that restorative responses to nature under conditions of cognitive fatigue and stress include attention restoration and stress reduction (Bowler et al., 2010; Hartig et al., 2014; Kondo et al., 2018). The mechanisms through which nature experiences leads to renewed adaptive resources (i.e., 'restoration'), however, remain unclear. Whereas numerous studies document salutary affective, cognitive, and physiological effects of nature experiences, little experimental work has directly assessed the interplay of attention restoration, stress reduction, and other processes underlying nature's benefits.

In addition to experimental studies, a growing body of observational research investigates cumulative restoration (from cognitive fatigue and stress) as a pathway(s) through which access to natural environments, especially greenspace, can lead to positive mental and physical health outcomes (Hartig et al., 2014; James et al., 2015). Although epidemiologic work provides evidence of associations between nature and health, few studies use longitudinal designs or directly assess attention restoration or stress reduction as pathways to improved health (Hartig et al., 2014). The causal role of stress reduction/attention restoration in long-term health outcomes, therefore, remains unclear.

Attention Restoration Theory (ART). Substantial research investigates whether experiences with nature can improve cognitive functioning and facilitate recovery from fatigue (Bowler et al., 2010; McMahan & Estes, 2015). Early research on the relation between views from windows and attention provided preliminary evidence supporting ART (Kaplan, 1995; Tennessen & Cimprich, 1995). Tennessen and Cimprich (1995) find that college students with more natural views from dormitory windows show greater ability to direct attention than students with less natural views. More recent research includes experimental designs that induce cognitive fatigue before exposing participants to different environments to facilitate detection of differential restoration. Using this experimental paradigm, some laboratory-based studies provide evidence of renewed attentional capacity following exposure to virtual natural environments (e.g., images, videos of nature), relative to urban environments. For example, Berto et al. (2005) find that participants who viewed images of nature showed improved performance on a sustained attention, whereas participants who viewed images of urban environments or geometric shapes showed no change (Berto, 2005).

Further support for ART derives from experimental studies that assess attention restoration in varied field settings. Several studies examine whether participants show changes in self-report and attentional performance measures before and after walking in a natural or urban environment (e.g. Hartig et al., 2003). Berman et al. (2008) find that participants with depleted attentional capacities prior to environmental exposure showed gains in directed attention and executive function abilities following a 50-minute walk in a tree-lined urban park. Participants who walked in a downtown metropolitan area, however, showed no improvement on attentional performance measures (Berman et al., 2008). Hartig et al. (2003), moreover, find that participants who walked for 50 minutes in a wildlife nature preserve showed improved performance on an attention task, whereas participants who walked in an urban setting showed a decline in performance (Hartig et al., 2003).

Findings of experimental field studies also show that attention restoration can occur in a wide range of settings, from mountain trails to urban micro-parks. Hartig et al. (1991) find that vacationing in a wilderness area can promote recovery from attention fatigue, but other studies demonstrate cognitive benefits arising from more modest doses of urban nature. In a study of public housing residents in a poor inner-city neighborhood in Chicago, Kuo (2001) finds that residents of a high-rise building bordered by grass and trees performed better on attentional tasks and reported greater effectiveness in managing major life issues, compared to residents of an otherwise identical high-rise building surrounded by concrete and asphalt. A study of children in this inner-city public housing project, moreover, finds that children living in apartments with nearby nature demonstrated greater concentration and impulse control than those living in apartments with barren surroundings (Taylor et al., 2002).

Stress Recovery Theory (SRT). Evidence of SRT indicates that, under conditions of acute or chronic stress, experiences with nature can lead to rapid, positive shifts in mood, accompanied by reductions in physiological activity. Like experimental research guided by ART, studies that assess autonomic (e.g., affective, physiological) responses to nature often include a controlled stress-inducing manipulation prior to environmental exposures. In an early laboratory study of SRT, participants viewed a stress-inducing video about prevention of work accidents, followed by images of natural or urban environments. Results show that participants who viewed images of nature recovered quicker and more completely from psychophysiological stress, as demonstrated by the timing and magnitude of changes in positive and negative affect and physiological activity (Ulrich et al., 1991).

A recent systematic review, moreover, identified 43 non-laboratory experimental studies of stress recovery during nature experiences, including nature viewing, urban nature walks, outdoor exercise, and gardening (Kondo et al., 2018). Much reviewed work included early studies of the Japanese practice of restoration in forests, called *shinrin-yoki* (or 'forest bathing'), but more recent research in the US and Europe examined exposure to natural features in urban settings (e.g., urban parks). Most research in this area used both anthropometric measures of cardiovascular activity and self-report measures of affect to assess changes in physiologic and psychological stress levels. Kondo et al. (2018) report that studies which assessed changes in heart rate and blood pressure, as well as self-report changes in affect, provide the strongest evidence of stress recovery in natural field settings. Overall, these studies show reduced cardiovascular activity, increased positive affect, and decreased negative affect following experiences with nature (Kondo et al., 2018).

Epidemiological Research

Experimental studies provide evidence of psychological and physiological restoration following experiences with nature that vary by setting, activity, and duration. Building on this literature, growing epidemiologic research examines the role of residential greenspace in health, theorizing cumulative restorative effects of nearby nature as a potential underlying mechanism (Hartig et al., 2014). In this section, I review epidemiologic evidence of relations between nearby nature and population-level health outcomes related to stress and cognitive fatigue.

Stress and Health. Much work suggests that stress plays a role in myriad psychiatric and physical morbidities (Cohen et al., 2007). Physiologic responses to environmental stimuli or psychosocial conditions that an individual perceives as stressful include the release of glucocorticoids (e.g., cortisol), a class of steroid hormones that mediate the stress response (Cohen et al., 2007). Whereas glucocorticoid responses to acute stress serve an adaptive function, repeated or chronic stress prolongs exposure to glucocorticoids, which may contribute to the onset of pathologies (Anderson & Armstead, 1995). For example, chronic exposure to high levels of glucocorticoids corresponds with elevated risk of depression and cardiovascular disease (Anderson & Armstead, 1995).

Extensive research in both animal and human studies also indicates that stress during pregnancy can lead to increased risk of adverse birth outcomes (Beijers et al., 2014; Hobel et al., 2008). Longitudinal studies show strong associations between maternal prenatal psychosocial stress (e.g., exposure to acute stressors, man-made or natural disasters, subjective perceptions of stress) and risk of preterm birth (PTB), small-for-gestational age (SGA), and low birth weight (LBW; Austin & Leader, 2000; Hedegaard et al., 1993; Rondó et al., 2003). Although the mechanisms underlying relations between prenatal stress and adverse birth outcomes remain less clear, much work implicates increased activation of the hypothalamic-pituitary-adrenal (HPA) axis and elevated intrauterine and fetal cortisol concentrations (Beijers et al., 2014).

Strong observational evidence of nature's potential restorative effects derives from recent studies of salivary cortisol in individuals living in more or less natural areas. This small, but growing body of research examines the stress response in relation to long-term exposure to residential environments. Research in this area generally shows healthier patterns and lower mean concentrations of cortisol in residents of greener neighborhoods (Kondo et al., 2018). In a study of residents living in disadvantaged urban neighborhoods in the UK, Roe et al. (2013), find that higher levels of residential greenspace vary with steeper (healthier) diurnal cortisol decline.

Nature and Stress-Related Outcomes. Consistent with theories of restorative environments (ART, SRT), nearby nature may reduce the risk of stress-related diseases among residents by reducing psychophysiological stress levels. Few epidemiologic studies, however, directly examine whether restoration from cognitive fatigue or stress serves as a mediator of nature/health relations, such that greater access to nature engenders cumulative 'restoration' and, in turn, improves health. Given that little epidemiologic work on nature and health employs longitudinal methods that can examine temporal order of events, research exploring mediation generally assesses whether observed relations between nearby nature (e.g. greenspace) and proposed mediators can 'explain' overall nature/health associations that are derived from cross-sectional study designs.

Baron and Kenny's (1986) procedure enjoys popular use in this literature to establish mediation in associations between nature and health. According to Baron and Kenny (1986), to function as a mediator, the proposed mediator should vary independently with nearby nature and the health outcome of interest. In addition, control for the potential mediator should reduce the strength of the overall association between nature and health (Baron & Kenny, 1986). In a study using Baron and Kenny's (1986) procedure to examine the mediating role of stress, de Vries et al.

(2013) find that lower stress can partially explain the positive association between streetscape greenery and perceived general health.

In addition, substantial cross-sectional research finds overall associations between nature and psychological health, including lower perceived stress and reduced risk for psychiatric morbidities in greener neighborhoods. For example, epidemiologic evidence indicates that neighborhood greenspace varies inversely with self-perceived stress (Stigsdotter et al., 2010), severity of depressive symptoms, and prevalence of clinical anxiety and depression (de Vries et al., 2013; Fan, Das, & Chen, 2011; Nutsford et al., 2013; Triguero-Mas et al., 2015).

Further cross-sectional evidence shows relations between neighborhood greenspace and physical health indicators, including lower odds of coronary heart disease (Maas et al., 2009) and lower systolic and diastolic blood pressure (Markevych et al., 2014). In addition, cross-sectional research finds consistent associations between neighborhood greenspace and reduced risk of adverse birth outcomes (Donovan et al., 2011; Dadvand et al., 2014). Residential greenness varies positively with birth weight (Agay-Shay et al., 2014; Dadvand et al, 2012, 2014; Markevych et al., 2014) and inversely with the risk of preterm birth (PTB) (i.e. delivery <37 weeks gestation) and small-for-gestational age (SGA) (i.e. birth weight <10th percentile by gestational age and sex) (Hystad et al., 2014).

Nature as a Stress-Buffer. Differential exposure to stress in low- versus high-socioeconomic position (SEP) populations may explain income-related health disparities, given that low SEP varies with chronic activation of the stress response (Anderson & Armstead, 1995). A study of school-aged children in Montreal finds that lower-SEP children have higher salivary cortisol levels than higher-SEP children (Lupien et al., 2000). Accordingly, in addition to studying 'main' associations between residential greenspace and stress-related health outcomes, some epidemiologic research examines whether greenspace operates as a 'stress-buffer,' whereby greenspace exposure attenuates the pathogenic influence of low SES on health (e.g., Wells & Evans, 2003).

A growing body of observational research supports the 'stress-buffering' hypothesis of nature, suggesting that neighborhood greenspace may protect against the deleterious influence of low-SEP on physical and mental health. A population-level study in England finds that populations living in greener environments show smaller socioeconomic disparities in cardiovascular disease mortality than populations in areas with less greenspace (Mitchell & Popham, 2008). Research in a nationally representative sample of adults in Denmark, moreover, shows that greenspace 'buffers,' or moderates, the relation of stressful life events on poor perceived health (van den Berg et al., 2010). However, the cross-sectional design of research comparing associations between neighborhood greenspace and health in low- and high-SEP populations precludes establishment of a causal (protective) role of nature (Oakes, 2004). Longitudinal research that improves causal evidence of relations among nearby nature, SEP, and health, and identifies the specific characteristics of subpopulations to which nature confers benefits, holds relevance to efforts to reduce health disparities.

Nature and Attention-Related Outcomes. Additionally, some observational work has investigated relations of residential greenspace with attention-related health indicators. Kaplan (2001) examined relations between views around the home (i.e., from windows) and a measure of psychological wellbeing comprised of subscales intended to tap the emotional and cognitive manifestations of attention fatigue (e.g., distraction) and restoration (e.g., functioning effectively, feeling peaceful). Findings show an overall association between more natural views and wellbeing. Moreover, results suggest that different natural settings relate to different wellbeing sub-scales; for example, garden views (e.g., flowers, shrubs) vary with a sense of functioning effectively, whereas tree canopies vary with feeling at peace (Kaplan, 2001).

Given that experimental studies show reduced 'symptoms' of attention-deficit/hyperactivity disorder (ADHD)(e.g., inattention, impulsivity) following experiences with nature in non-clinical populations (Kuo, 2001; Taylor, Kuo, & Sullivan, 2002; Hartig et al., 2003), some researchers have also assessed whether nature confers benefits to ADHD-diagnosed populations. For example, a cross-sectional study in children diagnosed with ADHD finds that participation in outdoor/green activities varies inversely with the severity of ADHD symptoms (Kuo & Taylor, 2004).

Nature as a Behavior Setting

A large body of epidemiologic research explores whether nature in a residential context can promote health by shaping individual and social behavior (Hartig et al., 2014). Much work in this area focuses on two broad categories of behavior: physical activity and social support (or cohesion). In this section, I discuss epidemiologic research examining nature as a 'behavior setting,' and, in particular, evidence of physical activity and social behaviors as pathways leading from residential greenspace to health.

Physical Activity. Epidemiologic research suggests that neighborhood greenspace may provide environmental support for physical activity and, in turn, promote physical and mental health in residents (Hartig et al., 2014). Greenspace offers a venue for leisure-time physical activity, including recreational walking, cycling, and sports participation. Greener environments may also increase the likelihood that residents will choose to walk or cycle for utilitarian purposes (e.g. actively commute to work) by making routes to local destinations more aesthetically-pleasing (Hartig et al., 2014).

Cross-sectional research on the association between residential greenspace and physical activity shows inconsistent results (Hartig et al., 2014; James et al., 2015; Lachowycz & Jones, 2011). Some work finds positive relations between residential greenspace and physical activity, including overall physical activity (e.g., Richardson et al.,, 2013; Coombes et al., 2010) and walking or cycling for recreational or utilitarian purposes (e.g., Sugiyama et al., 2008). Other studies, however, find null or inverse associations between greenspace and physical activity (e.g., de Vries et al., 2013; Maas et al., 2008; Triguero-Mas et al., 2015). Findings of a Dutch population study indicate that residents of less green neighborhoods engage in more leisure-time walking and cycling than residents of greener neighborhoods (Maas et al., 2008).

Some epidemiologic work, moreover, uses mediation analysis methods (e.g. Baron & Kenny [1986], binary statistical techniques [see Ender, 2011]) to assess whether physical activity can explain relations between nature and different health outcomes. Observational research that tests the mediating role of physical activity in the association of nearby nature with psychological health shows mixed results. McEachan et al. (2016) find that greater physical activity partially explains the inverse association between residential greenspace and depressive symptoms in pregnant women. Sturm and Cohen (2014), conversely, find that physical activity cannot explain the relation between greater access to greenspace and reduced psychological distress.

Research on relations among neighborhood greenspace, physical activity, and obesity also produces mixed findings (James et al., 2015; Lachowycz & Jones, 2011). A large, population-level study in Denmark finds that greater access to greenspace corresponds with elevated odds of physical activity and reduced odds of obesity, although the researchers did not assess mediation (Toftager et al., 2011). However, other studies fail to demonstrate associations of greenspace with physical activity and obesity (e.g. Mowafi et al., 2012; Richardson et al., 2013; Witten et al., 2008; Cummins & Fagg, 2012; Picavet et al., 2016).

In response to inconsistent findings, several studies have assessed associations between physical activity and multiple types of greenspace to determine whether heterogeneity might arise from use of different greenspace measures. A study in England finds that physical activity varies positively with proximity to 'formal' green spaces (defined as having 'an organized layout and structured path network…'), but not 'informal,' 'natural,' or 'sport' green spaces (Coombes et al., 2010, p.818). These results suggest that features of structured green spaces, which commonly include organized walking trail networks, may provide a more effective venue for promoting recreational walking, cycling, and jogging (Kaczynski et al., 2008).

Social Behavior. Some research also examines associations between neighborhood greenspace and social cohesion, a community-level characteristic that describes shared norms, feelings of belongingness, and positive relationships among members (Hartig et al., 2014). Residential greenspace may promote social cohesion, by providing a venue for social gatherings where residents can develop and maintain social ties with neighbors (Lee & Maheswaran, 2011; Hartig et al., 2014). Cross-sectional findings suggest that residential greenspace varies with a stronger sense of community, more social contacts, and greater social support, particularly among the elderly, children, and low-SEP individuals who may rely more on their immediate community for social connections (Maas et al., 2009).

Previous research, moreover, demonstrates strong associations between positive social relationships and reduced morbidity and mortality (Holt-Lunstad et al., 2010). Accordingly, some epidemiologic work has also explored whether, by promoting social cohesion, residential greenspace may contribute to improved health. A small body of observational evidence indicates that social cohesion functions as a mediator in relations between residential greenspace and perceptions of mental, physical, and overall health (e.g., de Vries et al., 2013; Maas et al., 2009). Sugiyami et al. (2008) find that social cohesion partially explains the positive relation between perceived neighborhood greenness and self-rated mental health. The role of social cohesion in physical health benefits of nearby nature, however, remains less clear.

Nature as a Physical Environment

Nature can also function as a physical environment and influence health through the provision of ecosystem services. Natural environments rife with vegetation can improve the quality of air and water, regulate heat and humidity, and reduce noise exposure (Hartig et al., 2014).

Much work has focused on the role of natural environments in reducing air pollution (Hartig et al., 2014; Markevych et al., 2017). Evidence suggests that green vegetation (e.g., trees and forests) effectively removes air pollutants, including ozone and particulate matter, which increase the risk of morbidity (e.g., adverse birth outcomes, asthma, cancers) and mortality (Nowak et al., 2014). Research in pregnant women finds that higher surrounding greenness varies with lower levels of personal exposure to pollutants in and around the home (Dadvand et al., 2012).

Some evidence also suggests that green vegetation can reduce energy demands by providing shading and heat insulation in summer and winter months, respectively, thus indirectly benefiting air quality (Brack, 2002). In addition, by minimizing heat exposure, greenspace can reduce heat-related mortality, particularly among the elderly and other vulnerable populations (Gronland et al., 2015). Greenspace, moreover, can reduce harmful noise exposure by providing a physical barrier (e.g., green roofs and facades) and increasing psychological distance to the noise source (Gidlöf-Gunnarsson & Öhrström, 2007; van Ranterghem et al., 2015).

Gaps in the Literature

Causal Inference

Substantial epidemiologic research finds associations between residential greenspace and health. Few studies, however, use longitudinal designs that establish temporal order between environmental exposures and outcomes (i.e., that increased access to nature precedes improvements in health). Limitations of existing epidemiologic work include that populations with pre-existing morbidity may 'select' out of greener neighborhoods (Glass & Bilal, 2016; Oakes, 2004; Oakes & Rossi, 2003). Similarly, healthier individuals may seek out more natural settings, thus leading to a cross-sectional association between residential greenspace and health but shedding little insight on the potentially causal role of nature. As such, selection into neighborhoods presents a key rival explanation for cross-sectional research on greenspace and health (Oakes, 2004).

Heterogeneity in Nature/Health Relations

Little epidemiologic work examines effect modification in nature/health relations by individual or environmental factors. A small body of evidence suggests that disadvantaged populations may benefit more from residential greenspace than 'advantaged' populations (e.g., Mitchell & Popham, 2008). Disadvantaged populations may have greater exposure to acute and chronic stressors, as indicated by different cortisol concentrations and patterns in low- vs. high-SEP populations (Anderson & Armstead, 1995; Lupien et al., 2000). According to psychoevolutionary framework (Ulrich et al., 1991), access to greenspace, therefore, may foster more 'restorative' experiences (e.g., recovery from psychophysiological stress) and, in turn, reduce the risk of physical and psychiatric morbidities among lower SEP, but not higher SEP, groups.

The 'stress-buffering' hypothesis of nature, which holds that nearby nature protects against the pathogenic influences of stress on health, requires further refinement and empirical testing. It remains unclear whether lower-SEP or racial/ethnic minority populations benefit more from nature in general, or only from certain types of nature and for certain health outcomes. For example, relatively consistent evidence in lower-SEP groups shows stronger beneficial associations of residential greenspace with birth outcomes (e.g., Dadvand et al., 2012; 2014) and perceived general health (e.g., Maas et al., 2006; de Vries et al., 2003). Conversely, evidence suggests that for some nature/health associations, such as proximity to greenspace and obesity, nature's benefits appear to accrue to higher-SEP populations, and exclude disadvantaged and minority groups (e.g., Scott et al., 2009; Morgan Hughey et al., 2017).

In addition, little work has identified the specific dimensions of SEP that hold relevance for relations between nature and health. Whereas some work has broadly examined whether nature/health associations vary by level of neighborhood socioeconomic status (SES) (e.g., Mitchell & Popham, 2008), fewer studies have tested for effect modification by individual sociodemographic characteristics, including race/ethnicity (Hartig et al., 2014). Differences in preferences for, and barriers to, greenspace may influence the extent to which racial/ethnic minorities or individuals of lower SEP access, use, and benefit from certain types of natural environments (Agyemang et al., 2007; Morgan Hughey et al., 2017). Research in the UK suggests that low-income adults, for example, use natural settings such as parks less than do those of higher income, owing to individual (e.g., financial costs, lack of leisure time) and social/cultural reasons (e.g., lack of awareness and attractive options for green activities) (Morris, 2003).

The role of nearby nature in health, including how, for whom, and what types of nature confer benefits, remain unclear. I attempt to address several existing gaps in the literature by (1) moving beyond a cross-sectional approach and leveraging a sibling-linked longitudinal dataset to test whether *increases* in access to greenspace precede reductions in the risks of obesity and adverse birth outcomes, and (2) conducting theoretically motivated tests of effect modification in relations between nearby nature and health, including by race/ethnicity; and (3) assessing whether residential selection – a key threat to validity in studies of 'neighborhood effects' – confounds relations between greenspace and health.

CHAPTER 2

Green mobility and obesity risk: A sibling comparison design

Obesity in the US has shown a rapid rise in prevalence over time (Ward et al., 2019). Individually targeted behavioral interventions suggest only modest benefits (Michie et al., 2009). This minimal effectiveness has led researchers to explore the potential of improving neighborhood conditions. An ecological focus on, and change in, neighborhoods, researchers argue, may reduce exposure to 'obesogenic environments' (Lake & Townshend, 2006).

The configuration of the built environment may influence obesity risk by facilitating or constraining health behaviors and modifying physiological processes. For instance, neighborhood greenness, defined broadly as the total amount of greenspace in one's residential environment, may contribute to reduced obesity risk through several pathways (James et al., 2015; Markevych et al., 2017; Hartig et al., 2014). First, neighborhood greenness may encourage physical activity by providing a venue for leisure exercise such as recreational walking, cycling, and mixed-sports use (James et al., 2015). Greener environments may also encourage residents of urban areas to walk or cycle for means of transport by making routes to local destinations more aesthetically pleasing (Hartig et al., 2014). For example, in neighborhoods containing parks and grocery stores, residents with greater exposure to greenness show a higher frequency of walking and lower BMI (Tilt et al., 2007). Thus, neighborhood greenness may confer benefits to residents of urban areas conditional on access to nearby destinations by foot or bicycle.

Some studies find that the inverse association between greenness and weight remains after controlling for physical activity, suggesting the presence of other protective mechanisms (Astell-Burt et al., 2014; Villeneuve et al., 2018). Neighborhood greenness may contribute to better health by reducing stress, facilitating social cohesion, and improving health behaviors in addition to physical activity (Hartig et al., 2014; Markevych et al., 2017). For instance, exposure to greenness can help restore depleted psychological capacities which, in turn, may promote improved physiological functioning and healthier diet. Some measures of greenness correspond with environmental psychologists' assessments of 'restorative environments' (Rhew et al., 2011) — that is, natural environments that replenish cognitive resources and reduce stress (Berto, 2005; Kaplan, 1995). Evidence suggests that stress and cognitive fatigue adversely influence metabolic processes, leading to increased fat accumulation and obesogenic food behaviors (Holmes et al., 2010; Torres & Nowson, 2007; Zimmerman & Shimoga, 2014). Neighborhood greenness, therefore, may also reduce risk in that its presumed restorative benefits may affect physiological processes and food behaviors that contribute to obesity.

Previous work, based mostly on cross-sectional data, reports a protective association between neighborhood greenness and obesity (Ellaway et al., 2005; Klompmaker et al., 2018; Pereira et al., 2013; Toftager et al., 2011). A systematic review reports that over two-thirds (68%) of studies show at least one association in the expected direction between greenness, behavioral mechanisms (e.g., physical activity), and obesity or related health outcomes (e.g., diabetes) (Lachowycz & Jones, 2011). A large, population-level study in Denmark, for example, shows that greater access to green space varies positively with physical activity and inversely with obesity risk (Toftager et al., 2011). A study in eight European countries also finds that residents of urban areas with high levels of greenness have a 40% lower risk of obesity than do residents of areas with low greenness (Ellaway et al., 2005).

Whereas some studies find null (e.g. Mowafi et al., 2012; Richardson et al., 2013) or positive (e.g. Cummins & Fagg, 2012; Picavet et al., 2016) associations between neighborhood greenness and obesity, the evidence generally points to protective effects (James et al., 2015; Lachowycz & Jones, 2011). If one assumes an inverse association between neighborhood greenness and obesity, then efforts to increase greenness may reduce obesity risk among residents. However, most evidence of greenness / obesity relations derives from cross-sectional studies which pose several challenges to causal inference.

Scholars note the susceptibility of cross-sectional designs to various biases (Hartig et al., 2014; James et al., 2015). Higher levels of greenness in the residential environment, for example, may correlate with other social and economic factors that reduce obesity risk. Studies often attempt to control for these factors, but it remains unclear which variables researchers should include to effectively account for confounding (van den Berg et al., 2015).

Additionally, residential selection, in which healthier residents choose to live in less obesogenic neighborhoods, remains a powerful confounder that cannot be assessed in cross-sectional work (Glass & Bilal, 2016; Oakes, 2004). More physically active individuals may selectively move to greener neighborhoods that offer greater opportunities for physical activity. Health or economic constraints, alternatively, may confine individuals with pre-existing obesity to less green neighborhoods (Hogendorf et al., 2019).

Cross-sectional work, moreover, cannot disentangle temporal order between exposure (e.g., neighborhood greenness) and outcome (e.g., obesity risk). This leaves open the question of whether increases in greenness precede reductions in obesity. For these reasons, cross-sectional research alone cannot inform interventions to improve the health-promoting capacity of the residential environment.

Current Study & Hypotheses

In this study, I move beyond previous identification strategies by using a unique sibling-linked dataset created from the California birth files to track mothers with two births between 2007 and 2015. I analyze longitudinal data on residential address, greenness, and height and weight to estimate, using a sibling comparison approach, whether a change in neighborhood greenness precedes a change in obesity risk.

This approach offers several advantages over previous cross-sectional work (Hutcheon & Harper, 2019). First, the longitudinal analysis of sibling-linked data controls for any time-invariant variables including genetic and socioeconomic factors that affect the risk of obesity. Whereas other models require researchers to adjust for these factors (which often remain unmeasured), this approach permits estimation of effects of greenness without measuring all confounders that remain fixed. Next, by leveraging data on the health characteristics of mothers collected at two time points, I can examine the influence of neighborhood greenness while controlling for preexisting morbidity, as well as assess the role of health selection in residential moves. Finally, in contrast to previous cross-sectional work, I examine whether and to what extent *changes* in neighborhood greenness confer health benefits to residents. To this end, results can inform evidence-based practices, policies, and programs that aim to reduce obesity risk by changing current levels of greenness in the residential environment (Hogendorf et al., 2019).

I focus this analysis on mothers living in urban neighborhoods, given that health behaviors and outcomes may differentially relate to neighborhood greenness in urban versus rural areas (e.g., Laurent et al., 2019). In line with longitudinal work that examines socioeconomic mobility – or moving away from or toward disadvantage – I characterize a change in urban neighborhood greenness as 'green mobility.' I analyze associations between changes in urban neighborhood greenness and obesity risk in two subpopulations: (1) mothers in California who move to a 'new' neighborhood, and (2) mothers who do not move but experience within-neighborhood changes in greenness over time. Based on previous cross-sectional work, I hypothesize that mothers with upward green mobility (i.e., those who experience positive changes in neighborhood greenness) will show a lower-than-expected risk of obesity, whereas mothers with downward green mobility will show an increase in the risk of obesity.

Methods

Variables and Data

I retrieved individual-level data from the California Department of Public Health (CDPH) birth files for years 2005-2015. The birth file includes data on over 99.99% of births in California. Prior literature describes the quality and provenance of these data (*Birth Registration Handbook*, 2016; Gould, 1999). Importantly, the birth file also provides geographic information on mother's residential address, which I used to link individual-level data with a census-tract level measure of neighborhood greenness and disadvantage (described below). The State of California and the University of California, Irvine approved this study (IRB protocol approval # 13-06-1251 and 2013-9716, respectively).

Sibling Linkage Strategy

The California birth files include records for 5,814,502 births in years 2005-2015. I first excluded from the analytic sample records of non-singleton birth events (N=185,930), as multiple births interfere with the logic of the sibling linkage. I also excluded records missing data on requisite variables needed to perform the linkage strategy, including mother's date of birth (N=2,183), last name (N=24,502), and first name (N=2,934). I used Link Plus (version 3.0), an open-source probabilistic record linkage program developed at the Division of Cancer Prevention within the Centers for Disease Control and Prevention, to identify consecutive live singleton births to the same mother during the study period.

Link Plus implements a probabilistic record linkage algorithm developed by Fellegi and Sunter (1969), called the Fellegi-Sunter methodology; the formal mathematical models involved in this methodology underpin most modern record linkages (see Herzog and Scheuren 2007 for review). A recent study (Avoundjian et al. 2020) comparing linkage methods commonly used in public health reports that programs based on the Fellegi-Sunter method (including, but not limited to, Link Plus) maximize the number of true matches identified, given their high degree of sensitivity (i.e., the proportion of true matches identified by the algorithm) and precision (i.e., the proportion of matches identified by the algorithm that were true matches). By contrast, programs based on deterministic matching algorithms exhibit high precision but low sensitivity, and thus perform poorly when using lower quality data (i.e., misspelled or missing fields). Such programs may induce systematic bias due to the exclusion of record-linkages for lower SEP and racial-ethnic minority populations (Bohensky et al. 2010).

In general, Link Plus proceeds through the following steps. First, the program identifies potential matches by 'blocking' record pairs with exact values on a user-specified field. These comparison-pairs then receive a match score based on similarity of specified 'match' variables; pairs with higher scores appear more likely to reflect 'true' matches. Next, the user sets a lower-bound match score, above which he / she / they can review pairs and assign designations of 'true match,' 'uncertain,' or 'no match.' Pairs with match scores below the specified lower-bound receive a 'no match' designation and are dropped.

For this study (and the following chapters), I used Link Plus to 'block' records on maternal date of birth. Potential matches (i.e., all record pairs with the same maternal date of birth) then received match scores according to the similarity of maternal first and last name and paternal date of birth. Match scores ranged from 0 (pairs with the same maternal date of birth but differing on all other variables) to 25 (pairs matching on all variables). In order to consider a broad range of matches and avoid dropping potential low-scoring 'true matches,' I set a lower-bound match score of 5.0, above which comparison-pairs received a temporary designation of 'uncertain.'

Next, I sorted 'uncertain' comparison-pairs into categories. I assigned pairs matching on all variables (maternal first and last name and paternal date of birth) to a primary category of 'true matches' and included these pairs in the analytic sample without further review. I categorized pairs matching on maternal last name and paternal date of birth (but not maternal first name) to a secondary category, and those matching on maternal first and last name (but not paternal date of birth) to a third. I excluded from review comparison-pairs not included in these three categories. For pairs in the latter two categories (matching on 2 out of 3 variables), I assigned a 'true match' designation only to those for whom the date of birth for record 1 (first birth) corresponded with the date of last delivery for record 2 (second birth).

This process first yielded 1,970,246 'true match' sibling pairs, representing two consecutive birth events to the same mother. However, given that mothers may have more than two birth events over the study period, this dataset contained multiple sibling pairs delivered by the same mother (i.e., for a mother with 3 birth events, time 1 and time 2 siblings and time 2 and time 3 siblings constitute separate match pairs) resulting in duplicate mother records. Accordingly, I performed the linkage strategy using the same Link Plus configuration and decision rules (as described above) repeatedly to identify all consecutive live births to the same mother. This process yielded 1,340,676 mothers with at least two live births between 2005 and 2015.

Obesity

In 2007, California adopted the revised U.S. Standard Certificate of Birth, which instituted collection of maternal weight and height data from the certificate of birth (CDC, 2003). I therefore restricted the analytic sample to mothers with at least two consecutive births between 2007 and 2015 (n = 899,823) and with non-missing and plausible pre-pregnancy height (4'5" – 6'5") and weight (60 lb. – 350 lb.) data (N=797,936). I calculated prepregnancy body mass (BMI) as prepregnancy weight (kilograms) divided by height (meters) squared, at the time of each birth. I then applied, based on

World Health Organization (W.H.O) definitions, standard weight status categories of obesity (BMI $\geq$ 30.0) and overweight (25.0 $\leq$ BMI < 30.0) (2006).

Height and weight data in the birth files derive from medical records and, in the absence of other sources, from self-report. Previous work, however, shows a high degree of agreement between prepregnancy BMI data retrieved from birth files and the National Health and Nutrition Examination Survey (NHANES), which collects height and weight data through medical examination (Branum et al., 2014; Ogden et al., 2015). The mean and distributional characteristics of BMI among this sample appear comparable to a broader set of adult women in California (Krueger et al., 2014), including women of reproductive age (i.e., 18-40), regardless of pregnancy status, in the California Health Interview Survey (CHIS).

Geocoding

I geocoded mother's residential addresses using ArcGIS software version 10.4 (Redlands, California). I located point coordinates of addresses using a 2013 street directory and assigned a corresponding census tract in which these coordinates fell based on 2010 US Census geography. Census tracts, a proxy for neighborhoods, are relatively permanent geographical subdivisions of a county. In the US, census tracts generally correspond to a buffer with approximately a 0.8-mile radius and contain 4,000 residents. Census tracts in California are, on average, slightly smaller (0.5-mile radius) and more populous (4,500 residents) (US Census Bureau, 2010).

I excluded record linkages in which the residential address failed to reach a minimum location match score of 80 percent or with unknown, missing, or non-California census tracts (N=97,276). I further restricted the sample to mothers living in urban California census tracts (6,540 out of 8,057 census tracts). This process resulted in an analytic sample of 552,929 mothers with valid obesity and geographic data at two time points in urban California census tracts. The mean number of mothers in a census tract by year (2007–2015) is 55 (standard deviation = 44), with a range of 1 to 566 mothers per tract-year.

Green Mobility

I retrieved data on neighborhood greenness from the NOAA Climate Data Record (CDR) Normalized Difference Vegetation Index (NDVI) remote sensing product. The NDVI CDR measures and summarizes surface vegetation activity across the globe and enjoys widespread use in epidemiological studies (Bell et al., 2008; Hystad et al., 2014; Rhew et al., 2011). NOAA calculates NDVI using the spectral bands in the red and near infrared wavelengths (see Formula 1), derived from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar orbiting satellites. This NDVI CDR product obtains data from 8 orbiting satellites and generates daily measurements of NDVI on a 0.05°x0.05° grid from January 1, 1981 to 10 days before the user-inputted date.

Formula 1. NDVI=(NIR-RED)/(NIR+RED)

I applied Google Earth Engine to create an average annual NDVI measure for each urban census tract in California between 2007 and 2015. I achieved this result by filtering the NDVI daily images to the desired year and selecting the 'NDVI' band. I used the reduceRegion command, which applies a 'reducer' to all pixels in a specific region, to calculate the mean of all pixels within each census tract. This process resulted in one mean NDVI measure per census tract-year. Consistent with other epidemiologic studies of neighborhood greenness and health (Hystad et al., 2014; Sarkar, 2017), I created quartiles of census tract-level NDVI to account for potential non-linear greenness/obesity relations for use in primary analyses (sensitivity tests specified as the key independent variable continuous change in NDVI, described below). Figure 2.1 shows a choropleth map of neighborhood greenness in the Greater Los Angeles Area in 2010 to give the reader a sense of the distribution of quartile-level NDVI.

I next defined the key independent variable, green mobility, using the two time points of neighborhood information available in the sibling linkages. To capture the largest population of mothers in the analytic sample, I estimated green mobility between time 1 (first birth) and time 2 (second birth), rather than between subsequent sibling-pairs. I created a categorical 'green mobility' measure by classifying mothers according to changes in quartile of neighborhood greenness from time 1 to time 2, due either to moving to a new neighborhood, or, among mothers who did not move, to within-neighborhood changes in greenness.

Among mothers who moved to a new neighborhood between time 1 and time 2 (N=253,560), I defined changes from low to high quartiles of neighborhood greenness (i.e., a move to a greener neighborhood) as upward green mobility, and changes from high to low quartiles of neighborhood greenness (i.e., a move to a less green neighborhood) as downward green mobility. I further disaggregated categories of upward and downward green mobility by the magnitude of quartile-level change in greenness. Strong upward green mobility captures an increase of three quartiles in neighborhood greenness (i.e., a move from Q1 to Q4), whereas moderate upward green mobility and low upward green mobility capture an increase of two, and one, quartile, respectively. I coded downward green mobility in a similar manner to upward green mobility, but in the inverse (i.e., a move from Q4 to Q1 represents strong downward green mobility). I categorized mothers who moved to neighborhoods within the same quartile of neighborhood greenness as 'laterally' mobile and used this group as a referent in analyses.

For mothers who did not move between births (N=299,369), I used the same logic to define the key independent variable according to the magnitude of within-neighborhood change in greenness over time. Analyses in mothers who did not move used as the referent group mothers living in neighborhoods that did not exhibit quartile-level changes in greenness between time 1 and time 2.

I conducted additional tests using a continuous metric, 'change in NDVI,' as the key independent variable. I calculated this measure as NDVI at time 2 minus NDVI at time 1. Values range from -1 to 1, where positive values represent increases in NDVI.

Neighborhood Disadvantage

I merged individual-level data and measures of neighborhood greenness and green mobility with a census tract-level measure of neighborhood disadvantage. I, consistent with past work, calculated an index of neighborhood disadvantage using six variables retrieved from the 2010 US Decennial Census: the proportion of households with income <$15,000, the proportion of households with income ≥$50,000 (reverse coded), the proportion of families in poverty (e.g., <$22,314 for a family of four in 2010), the proportion of households receiving public assistance (e.g., Supplemental Nutrition Program [SNAP]), the total unemployment rate, and the proportion of vacant housing units (Cronbach's alpha = 0.92). I standardized each variable and performed exploratory factor analysis to arrive at a composite indicator of the neighborhood disadvantage index. I then categorized neighborhood disadvantage into quartiles, where quartile 4 (Q4) represents the most disadvantaged quartile while Q1 represents the least disadvantaged quartile.

Analytic Approach

My tests turn on whether mothers who move to greener (or less green) neighborhoods exhibit a risk of obesity that differs from expected levels. I conducted separate analyses in movers and stayers given that these mothers may experience different types of changes in greenness (due to within- versus between-neighborhood variation). I estimated the conditional logit (i.e., log-odds) of obesity at time 2 as a function of green mobility (i.e., quartile-level change in neighborhood greenness), controlling for obesity status at time 1 (yes/no) to model change in the risk of obesity.

All models controlled for individual-level time-varying demographic and socioeconomic characteristics, including age (categorized as <20, 20-24, 25-29, 30-34, 35-39, >=40 years), education (less than high school, high school, some college or more), and insurance type (private insurance, Medicaid, other).

The sibling comparison design, which uses a mother as her own control, effectively adjusts for characteristics of mothers that do not change over time. However, moving may have a direct effect on, or signal changes in, mothers, such that a different set of individual or neighborhood factors influence obesity risk at time 2 (after moving) relative to time 1 (before moving). Accordingly, in analyses of mothers who moved, I additionally controlled for neighborhood disadvantage at time 2 and change in neighborhood disadvantage from time 1 to time 2.

Sensitivity Analyses

The stratification of mothers into categories of strong, moderate, and low upward and downward green mobility reduces statistical power, results in relatively large standard errors, and cannot account for changes that do not exceed quartile-level thresholds. Therefore, I repeated analyses but used a continuous change score of neighborhood greenness, where positive values represent increases in greenness from time 1 to time 2, to predict obesity risk.

I also assessed the potential for health selection in the green mobility / obesity association among mothers who moved to a new neighborhood. Healthier mothers may choose to live in neighborhoods that offer more health-promoting resources; conversely, obesity may directly or indirectly (i.e., through relations with SEP) confine mothers to less green neighborhoods. Accordingly, I examined whether obesity at time 1 relates to subsequent upward green mobility among mothers who moved.

In addition, I assessed, among mothers who did not move, the role of time between births. Within-neighborhood variation in greenness may increase over time, resulting in a stronger relation with obesity risk. For example, Figures 2 A, B, and C show change in neighborhood greenness (percent change in NDVI) between 2007 and 2010, 2010 and 2015, and 2007 and 2015, respectively, in Los Angeles (and the surrounding area). A greater proportion of census tracts show increases or decreases in greenness across the full 9-year study period from 2007 to 2015 (Figure 2.2C), relative to the shorter time periods from 2007 to 2010 (Figure 2.2A) and 2010 to 2015 (Figure 2.2B). This difference implies that mothers with longer intervals between births may experience greater changes in neighborhood greenness. As such, I repeated analyses among stayers but additionally adjusted for the interpregnancy interval between birth at time 1 and conception at time 2.

Finally, to account for clustering of mothers within neighborhoods, I applied generalized linear mixed models with random intercepts corresponding to mean levels of obesity in each neighborhood to estimate obesity risk at time 2 as a function of change in NDVI.

Results

Table 2.1 shows characteristics of the full analytic sample at time 1 and time 2. At time 1, approximately half of mothers had private health insurance coverage (51.8%), received WIC (49.7%), attained at least some college education (52.6%), and identified as Hispanic (48.0%). Nearly 24% of mothers reported having overweight and an additional 17% reported having obesity at baseline. At time 2, mothers showed increases in age and educational attainment, whereas the fraction of mothers with private health insurance and WIC remained relatively stable. Mothers on average exhibited increases in the prevalence of overweight (26.3%) and obesity (22.6%), consistent with previous work on pregnancy weight gain and retention with greater parity.

Table 2.2 shows changes in neighborhood greenness among mothers who moved (N=253,560) and did not move (N=299,369). Among mothers who moved, 51.0% moved 'laterally' to neighborhoods within the same quartile of greenness, 23.9% moved 'downward' to less green neighborhoods, and 25.1% moved 'upward' to greener neighborhoods. Compared to mothers who moved to a new neighborhood, a higher fraction of mothers who did not move experienced no (quartile-level) change in greenness over time (61.9%).

Tables 2.3 shows the unadjusted prevalence of obesity at time 2 among movers (Table 2.3A) and stayers (Table 2.3B), arrayed by quartile of neighborhood greenness at time 1 and time 2. Mothers who experienced no change in greenness (i.e., mothers who moved to neighborhoods within the same quartile of greenness or remained in neighborhoods that did not show quartile-level shifts in greenness) appear in the main diagonal, whereas off-diagonal cells comprise mothers who experienced increased or decreases in neighborhood greenness. For instance, among mothers who moved from neighborhoods with very low greenness (Q1) at time 1 to very high greenness (Q4) at time 2, the prevalence of obesity at time 2 is 21.4% (lower left-hand cell, Table 2.3A). By comparison, mothers who originated in and moved to neighborhoods with very low greenness (Q1) show an obesity prevalence of 25.8% (upper right-hand cell, Table 2.3A). Among mothers who did not move, those who lived in neighborhoods which increased from very low greenness (Q1) at time 1 to low (Q2) or high (Q3) greenness at time 2 also show lower obesity prevalence than mothers whose neighborhoods remain in the first quartile of neighborhood greenness at time 2.

As hypothesized, results of logistic regression analysis in mothers who moved to a new neighborhood show that upward green mobility (at all levels), relative to no change in neighborhood greenness, varies inversely with the odds of obesity at time 2 (Table 2.4, Model 1). Results, moreover, indicate an inverse gradient in the upward green mobility / obesity association (i.e., a dose-response) in that strong green mobility corresponds with a greater reduction in obesity odds

(odds ratio [OR]=0.89, 95% confidence interval [CI]: 0.80, 0.99) than moderate (OR=0.91, CI: 0.86, 0.96) or low (OR=0.93, CI: 0.90, 0.96) upward green mobility. I find no relation between downward mobility (at any level) and the odds of obesity. Inference for coefficients of covariates, including obesity at time 1 and time-varying individual socioeconomic and demographic characteristics, appears consistent with previous literature. Obesity at baseline, for instance, corresponds with a more than 35-fold higher risk of subsequent obesity. Public insurance (vs private insurance) and educational attainment of a high school diploma or less (vs some college) also vary with an increased odds of obesity, whereas parity of one previous births (vs two or more) and maternal age of less than 20 and greater than 30 years (vs 20-24 years) vary with lower odds of obesity.

Table 2.4 also shows results of analyses which further control for neighborhood disadvantage at time 2 (Model 2) and change in disadvantage from time 1 to time 2 (Model 3) among mothers who moved. Inference remains relatively unchanged from the original test and results support the observed dose-response relation between (increasing) levels of green mobility and (reduced) odds of obesity. However, in contrast to results of Model 1 controlling for only individual-level covariates, results of Model 2 and Model 3 show that low downward mobility also varies inversely with obesity risk.

Table 2.5 shows results of logistic regression analysis predicting obesity risk as a function of within-neighborhood change in greenness among mothers who did not move, controlling for obesity at time 1 and individual covariates. Findings indicate that a positive change of one quartile in greenness corresponds with lower odds of obesity (OR=0.94, CI: 0.91, 0.97). I find no association between any decreases in neighborhood greenness and obesity risk, although the direction of coefficients supports a potential relation between decreases in greenness and reduced obesity risk.

Sensitivity Tests

I estimated the risk of obesity as a function of continuous change in neighborhood greenness, given that categorizing mobility into quartiles reduces statistical power and may obscure effects of changes in greenness that do not exceed artificial thresholds. Results show an inverse association in both movers (Table 2.6, OR = 0.90, CI: 0.81, 0.99) and stayers (Table 2.7, OR = 0.79, CI: 0.69, 0.90).

I also examined the potential role of health selection in mothers who moved to greener neighborhoods. Results predicting green mobility as a function of time 1 maternal characteristics indicate a null relation between baseline obesity status and upward green mobility (OR = 0.98, CI: 0.96, 1.01; see Table 2.8). This finding suggests that health selection—at least, selection by obesity status— does not confound the observed association between upward green mobility and reduced obesity risk among movers.

Mothers with longer intervals between time 1 and time 2 may experience greater changes in within-neighborhood greenness. Thus, I included interpregnancy interval as a control in models estimating obesity risk as a function of upward, downward, and continuous green mobility among mothers who did not move. Inference for all analyses remained unchanged from the original tests.

Lastly, to account for clustering of mothers within neighborhoods, I fit a generalized linear mixed model that includes a dummy variable for each mother (i.e., a 'fixed effect') and random intercepts corresponding to mean levels of obesity in each neighborhood. Table 2.9 presents results of this mixed model; I find that a change in greenness varies inversely with obesity at time 2 (OR=0.82, CI: 0.71, 0.95), adjusting for maternal time-invariant factors, time-varying socioeconomic factors, and random neighborhood effects.

Discussion

Uncertainty remains as to the role of neighborhood greenness in an individual's risk of obesity. Cross-sectional work reports mixed results and cannot establish temporal order between neighborhood greenness and obesity. This analysis moves beyond cross-sectional estimates and minimizes confounding by using longitudinal data to examine whether increases or decreases in neighborhood greenness precede changes in obesity risk, controlling for stable unmeasured characteristics of mothers and obesity risk at baseline. This approach enables triangulation of epidemiological evidence by relying on distinct identification strategies and assumptions (Matthay et al., 2020). Findings indicate that mothers who experience upward green mobility exhibit a reduced risk of obesity. Additionally, results show a potential dose-response relation between green mobility and obesity in that larger increases in neighborhood greenness correspond with greater reductions in obesity risk. However, this *post-hoc* finding requires further refinement and testing before being taken as anything other than informed speculation.

Contrary to my hypothesis, I also find that small decreases in neighborhood greenness (i.e., low downward green mobility) correspond with reduced obesity risk. Moreover, although relations with larger decreases in greenness are not statistically detectable (i.e., the 95% CI contains 1.0), point estimates of less than 1.0 suggest that moderate and strong downward green mobility may also reduce obesity risk. Environmental barriers and personal experiences, such as poor public transportation, limited walkability, and safety concerns, may determine the extent to which residents access, use, and receive health benefits from neighborhood greenspace. I encourage future work that longitudinally examines individual and contextual effect modifiers to interrogate how neighborhood changes, *including decreases* in overall greenness levels, affect the health and wellbeing of residents.

Past work suggests that higher levels of greenness in the residential environment may improve health behaviors, reduce stress, and increase social cohesion (Hartig et al., 2014;

James et al., 2015; Markevych et al., 2017). My findings cohere with the notion that one or more of these pathways may contribute to reduced obesity. At least one previous study using longitudinal data similarly finds a relation between increased greenness and reduced BMI in children (Bell, Wilson, & Liu, 2008) and several studies show positive associations of longitudinal changes in greenspace with physical activity (Hogendorf et al., 2019; Sugiyama et al., 2013). Results of the current study using longitudinal data suggest that the protective benefits of neighborhood greenness extend to reduced obesity risk in adults. This study also builds on past work examining environmental determinants of obesity, including access to supermarkets, in a similar sample of pregnant mothers in urban California neighborhoods (Gailey & Bruckner, 2019). Taken together, findings suggest that obesity in this population may respond to interventions that enhance the health-promoting capacity of natural and built residential environments.

Strengths of this study include the use of birth data from the California Birth Cohort files for years 2007 to 2015. These data afforded me a larger sample of adults to estimate associations of neighborhood greenness with obesity, relative to several smaller national (e.g. NHANES) and state (e.g. CHIS) surveys that enjoy widespread use. Given that many mothers had at least two births over the study period, I was able to perform a 'sibling link' on over 550,000 births, creating a longitudinal dataset with residential, health, and demographic information. Additionally, almost half of the mothers in the analytic sample moved to a new neighborhood between births, resulting in large changes in exposure to greenness. For instance, more than 32,000 mothers (12.6%) who moved show increases or decreases of at least two quartiles in neighborhood greenness (i.e., moderate to strong green mobility). This variation in the exposure may improve the efficiency of models to detect a relation between neighborhood greenness and obesity.

The unique study design, moreover, fills an important methodological gap in that it reduces the burden of confounding due to unmeasured factors that may bias cross-sectional work on the health benefits of neighborhood greenness. Sibling comparison designs, an extension of the matched case-control design, provide a within-mother (counterfactual) comparison of the relation between previously experienced levels of greenness (i.e., time 1 / before moving) and obesity risk. Given that a mother acts as her own control, this approach controls for stable characteristics that affect obesity risk across time. For example, time-invariant genetic factors that influence obesity risk are 'absorbed' using the sibling comparison design.

Limitations of this study include that it lacks information on the timing of residential moves. As such, I cannot, with precision, weigh the contribution of greenness levels in the 'new' neighborhood relative to the 'old' neighborhood. I attempt to address this issue by adjusting for the interval between time 1 and time 2 (i.e., mother's interbirth interval) as longer intervals may confer greater exposure to greenness levels in the new neighborhood. Future research with finer temporal resolution may yield important insights about the 'incubation period' from exposure to neighborhood greenness and the onset of changes in health behaviors (e.g., physical activity) and outcomes including obesity.

Although the study design reduces confounding due to time-invariant factors, a limitation of the sibling comparison approach involves confounding by factors not perfectly 'shared' (i.e., stable) across time. I attempt to reduce this confounding bias by controlling for time-varying characteristics of mothers, including age, insurance provider, and educational attainment. In some cases, however, the sibling comparison design may amplify confounding from factors that vary across time and cause both a change in exposure and outcome (Frisell et al., 2012; Frisell, 2020). For example, a significant life event, such as job displacement, may cause a mother to move to a less green but more affordable neighborhood. The financial burden and stress induced by job loss may also affect health behaviors that result in weight gain. As such, non-shared factors (e.g., a change in job status) may introduce bias by confounding on a common cause.

Given that the sibling comparison design may increase confounding due to non-shared factors, I analyzed, in addition to movers, mothers who remain in the same neighborhood across births, based on the logic that stayers experience fewer changes. An advantage of the analyses in stayers includes eliminating the possible rival hypothesis that moving (but not positive changes in greenness) leads to lower obesity risk. Results in stayers suggest that the association between increased greenness and reduced obesity risk is unlikely to be explained by time-varying factors that cause a mother to move, or by the act of moving.

Analyses in mothers who remain in the same neighborhood offer at least two additional strengths. First, a principal limitation of examining movers involves a lack of information about the timing of moves. Among mothers who do not move, however, I can measure within-neighborhood changes in greenness with annual resolution between births. Additionally, residential selection, in which healthier mothers may choose to move to less obesogenic (i.e., greener) neighborhoods remains a potential confounder. Whereas sensitivity tests conducted in mothers who moved indicate that obesity at time 1 does not predict subsequent green mobility, it remains possible that unmeasured social or health factors that influenced both the decision to move and the risk of obesity at time 2 may confound results. Conversely, a mother's decision *not to move* between time 1 and time 2 may reflect a stable set of characteristics related to where she chooses to live. As such, examining stayers minimizes the likelihood of bias induced by residential selection.

Other limitations of this study include that the measure of neighborhood greenness may misrepresent the spatial context in which mothers engage in physical activity (or other protective behaviors). A recent review examining GIS measures of greenness finds stronger associations with physical health in larger buffers surrounding the home (Browning & Lee, 2017). However, mean NDVI in a smaller granular catchment area or buffer surrounding a mother's address may yield more accurate estimates of greenness / obesity associations, particularly in areas where administrative boundaries do not represent residents' average activity space (Stark et al., 2014).

Vegetation indices, moreover, do not provide information about the quality or type of greenspaces in the environment. Environmental hazards like wastelands, for example, may appear green (from the perspective of satellite imagery) but are more likely to harm rather than benefit residents. Land-use datasets, which indicate the primary usage of greenspaces, may help explain the mechanisms underlying nature / health relations (James et al., 2015). Moreover, I encourage moving beyond land-use datasets and vegetation indices which enjoy widespread use in the field; the development of a neighborhood greenspace index that accounts for quality, type, accessibility, and total greenness levels appears warranted. This tool, if made publicly available, could significantly advance understanding of how, why, and for whom residential greenspace confers benefits.

In addition, since I lack information on mechanisms, I cannot compare the pathways through which within- versus between-neighborhood changes in greenness (i.e., in mothers who do not move and who do move, respectively) may differentially influence obesity risk. For example, moving to a new neighborhood may expose mothers to more accessible parks or aesthetically pleasing routes to nearby destinations, leading to increased physical activity. Conversely, among mothers who remain in the same neighborhood, the maturation of trees and other vegetation may enhance stress recovery. Though speculative, I view longitudinal assessments of specific mediators, including physical activity and psychological restoration, and their relations with different types of neighborhood greenness, as an important avenue for future research on greenness / obesity relations.

Finally, the focus on data gathered from birth certificates may limit the generalizability of findings. I used several sample restrictions to derive the analytic sample of approximately 550,000 mothers from over 1.3 million mothers with at least two consecutive births in California between 2005 and 2015. Another consideration regarding the external validity of findings includes that higher

BMI among women of reproductive age may reduce fertility as well as the probability of a successful pregnancy (Gunatilake & Perlow, 2011). For example, studies indicate higher risk of spontaneous abortion among mothers with BMI classified as overweight or obese (Fedorcsák et al., 2000; Lashen et al., 2004; Zain & Norman, 2008). The perinatal and maternal risks associated with higher BMI may lead to the underrepresentation of mothers with overweight and obesity in the study population. Findings of the current study, therefore, may pertain only to the mothers in the study sample, who appear, on average, to have slightly higher SEP and lower obesity prevalence than women in comparable populations.

Conclusion

This study used longitudinal data on mother's residential address and obesity status between 2007 and 2015 to estimate obesity risk as a function of census tract-level changes in greenness, or 'green mobility.' I used a sibling comparison design to control for unmeasured stable characteristics of mothers and adjusted for baseline obesity risk. Mothers who experienced positive changes in greenness show a lower-than-expected odds of obesity. Unexpectedly, small decreases in neighborhood greenness also show protective associations with obesity risk. Future work that investigates heterogeneity in relations, including how and for whom greenspace promotes health, can advance understanding of nature's benefits and inform neighborhood-level interventions.

Tables & Figures

Table 2.1. Characteristics of full analytic sample (N=552,929) at time 1 and time 2, 2007-2015.

	Time 1		Time 2	
Parameter	*n*	%	*n*	%
Education				
Less than HS	112,416	20.33	94,825	17.15
High school	131,395	23.76	130,646	23.63
Some college	290,667	52.57	308,542	55.80
Other	18,451	3.34	18,916	3.42
Insurance				
MediCAL	235,437	42.58	235,165	42.53
Private	286,670	51.85	287,620	52.02
Other	30,822	5.57	30,144	5.45
WIC receipt - yes	273,114	49.74	275,443	49.99
Race/ethnicity				
NH white	157,689	28.52	158,221	28.62
NH black	31,729	5.74	31,386	5.68
NH Asian	85,451	15.45	85,313	15.43
Hispanic	265,481	48.01	265,197	47.96
Other	12,579	2.27	12,812	2.32
Maternal age (years)				
<20	70,201	12.70	17,288	3.13
20-24	132,264	23.92	106,154	19.20
25-29	161,534	29.21	143,279	25.91
30-34	137,762	24.91	167,920	30.37
35-40	46,788	8.46	97,684	17.67
≥ 40	4,380	0.79	20,604	3.73
Weight status				
Underweight	26,942	4.87	19,260	3.48
Healthy	303,549	54.90	263,392	47.64
Overweight	130,089	23.53	145,156	26.25
Obese	92,349	16.70	125,121	22.63

Abbreviations: NH, non-Hispanic; Q, quartile; WIC, Supplemental Nutrition Program for Women, Infants, and Children.

Table 2.2. Change in neighborhood greenness among mothers who moved (N=253,560) and did not move (N=299,369) between time 1 and time 2.

	Movers		**Non-movers**	
Change in greenness	n	%	n	%
+3 quartiles	3,418	1.35	1,044	0.35
+2 quartiles	13,560	5.35	7,099	2.37
+1 quartile	46,713	18.42	48,541	16.21
No change	129,312	51.00	185,317	61.90
-1 quartile	45,491	17.94	48,997	16.37
-2 quartiles	12,458	4.91	7,304	2.44
-3 quartiles	2,607	1.03	1,067	0.36

Table 2.3. Unadjusted prevalence of obesity at time 2 in mothers who moved (top) and did not move (bottom), arrayed by quartile of neighborhood greenness at time 1 and time 2, where main down diagonal represents no change in greenness.

A. Mothers who moved (N=253,560)

		Time 1			
	Greenness	Q1	Q2	Q3	Q4
Time 2	Q1 (very low)	25.85%	23.18%	24.68%	23.32%
	Q2 (low)	22.31%	22.40%	23.05%	22.05%
	Q3 (high)	21.90%	22.35%	24.35%	23.74%
	Q4 (very high)	21.42%	20.23%	23.04%	23.45%

B. Mothers who did not move (N=299,369)

		Time 1			
	Greenness	Q0	1	2	3
Time 2	Q0 (very low)	25.20%	22.04%	20.09%	23.71%
	Q1 (low)	21.51%	20.90%	20.59%	20.39%
	Q2 (high)	19.36%	20.50%	22.15%	22.30%
	Q3 (very high)	25.00%	19.90%	20.72%	20.73%

Abbreviations: Q, quartile.

Table 2.4. Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of obesity at time 2 as a function of green mobility (vs. no change) in 253,560 mothers who moved between time 1 and time 2, controlling for obesity at time 1 and individual-level covariates (Model 1) and neighborhood disadvantage (Model 2) or neighborhood mobility (Model 3).

	Model 1			**Model 2**			**Model 3**		
Parameter	OR	95% CI		OR	95% CI		OR	95% CI	
Green mobility									
Strong downward	0.91	(0.81,	1.03)	0.91	(0.80,	1.02)	0.91	(0.81,	1.02)
Moderate downward	0.95	(0.90,	1.01)	0.96	(0.90,	1.01)	0.95	(0.89,	1.00)
Low downward	0.95	(0.92,	1.00)	0.95	(0.92,	0.98)	0.94	(0.91,	0.98)
Lateral (ref)									
Low upward	0.93	(0.90,	0.96)	0.95	(0.92,	0.99)	0.93	(0.90,	0.96)
Moderate upward	0.91	(0.86,	0.96)	0.94	(0.89,	0.99)	0.91	(0.86,	0.96)
Strong upward	0.89	(0.80,	0.99)	0.90	(0.81,	0.99)	0.89	(0.80,	0.99)
Obesity (time 1)	35.9	(34.9,	36.9)	35.1	(34.1,	36.2)	35.9	(34.8,	36.9)
Individual-level covariates									
Insurance									
Private (ref)									
Public	1.29	(1.25,	1.33)	1.15	(1.12,	1.19)	1.28	(1.24,	1.32)
Other	0.93	(0.88,	0.98)	0.87	(0.82,	0.92)	0.92	(0.87,	0.98)
Parity									
2 births	0.85	(0.83,	0.88)	0.89	(0.87,	0.92)	0.85	(0.83,	0.88)
≥ 3 births (ref)									
Age (years)									
<20	0.74	(0.69,	0.80)	0.74	(0.69,	0.79)	0.74	(0.69,	0.80)
20-24 (ref)									
25-29	0.98	(0.95,	1.01)	1.01	(0.98,	1.05)	0.98	(0.95,	1.02)
30-34	0.82	(0.79,	0.85)	0.89	(0.86,	0.92)	0.82	(0.80,	0.86)
35-39	0.73	(0.70,	0.77)	0.82	(0.78,	0.86)	0.74	(0.70,	0.77)
≥ 40	0.75	(0.69,	0.82)	0.84	(0.78,	0.92)	0.76	(0.70,	0.82)
Education									

Less than HS	1.19	(1.15,	1.24)	1.11	(1.07,	1.15)	1.19	(1.15,	1.24)
High school	1.26	(1.22,	1.30)	1.19	(1.15,	1.23)	1.26	(1.22,	1.29)
Some college (ref)									
Neighborhood-level covariates									
Disadvantage (time 2)									
Q1 (Very low; ref)									
Q2 (Low)	--			1.39	(1.33,	1.44)	--		
Q3 (High)	--			1.67	(1.60,	1.74)	--		
Q4 (Very high)	--			1.85	(1.78,	1.93)	--		
Economic mobility									
Strong upward (-3Q)	--			--			0.96	(0.88,	1.05)
-2 Q	--			--			0.92	(0.88,	0.96)
-1 Q	--			--			0.96	(0.93,	0.99)
No change (ref)									
+1 Q	--			--			0.99	(0.95	1.02)
+2 Q	--			--			1.08	(1.03	1.13)
Strong downward (+3Q)	--			--			1.16	(1.05	1.27)

Abbreviations: CI, confidence interval; HS, high school; OR, odds ratio; ref, referent; Q, quartile.

Table 2.5. Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of obesity at time 2 as a function of quartile-level change in neighborhood greenness from time 1 to time 2 in 299,369 mothers who did not move, controlling for obesity at time 1 and individual-level covariates.

Parameter	OR	95% CI	
Change in greenness			
-3 Q	0.83	(0.68	1.02)
-2 Q	0.93	(0.86	1.01)
-1 Q	0.98	(0.95	1.02)
No change (ref)			
+ 1 Q	0.94	(0.91	0.97)
+2 Q	0.96	(0.88	1.04)
+3 Q	1.09	(0.90	1.31)
Obesity (time 1)	49.6	(48.2	51.0)
Insurance			
Private (ref)			
Public	1.38	(1.33	1.42)
Other	1.04	(0.98	1.10)
Parity			
2 births	0.83	(0.80	0.85)
≥ 3 births (ref)			
Maternal age (years)			
<20	0.71	(0.66	0.77)
20-24 (ref)			
25-29	0.88	(0.85	0.92)
30-34	0.72	(0.70	0.75)
35-39	0.69	(0.66	0.72)
≥ 40	0.69	(0.64	0.73)
Education			
Less than HS	1.23	(1.18	1.28)
High school	1.34	(1.30	1.38)
Some college (ref)			

Abbreviations: CI, confidence interval; HS, high school; OR, odds ratio; ref, referent; Q, quartile.

Table 2.6. Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of obesity at time 2 as a function of continuous change in neighborhood greenness (NDVI) in 253,560 mothers who moved between time 1 and time 2, controlling for obesity at time 1, individual-level covariates, and neighborhood disadvantage at time 2.

Parameter	OR	95% CI
Change in NDVI	0.90	(0.81, 0.99)
Obesity (time 1)	35.1	(34.1, 36.2)
Insurance		
Private (ref)		
Public	1.15	(1.12, 1.19)
Other	0.87	(0.82, 0.92)
Parity		
2 births	0.89	(0.87, 0.92)
≥ 3 births (ref)		
Maternal age (years)		
<20	0.74	(0.69, 0.79)
20-24 (ref)		
25-29	1.01	(0.98, 1.05)
30-34	0.89	(0.86, 0.92)
35-39	0.82	(0.78, 0.86)
≥ 40	0.84	(0.78, 0.92)
Education		
Less than HS	1.11	(1.07, 1.15)
High school	1.19	(1.16, 1.23)
Some college (ref)		
Neighborhood disadvantage		
Q1 (Very low; ref)		
Q2 (Low)	1.38	(1.33, 1.44)
Q3 (High)	1.67	(1.60, 1.73)
Q4 (Very high)	1.85	(1.78, 1.93)

Abbreviations: CI, confidence interval; HS, high school; NDVI, Normalized Difference Vegetation Index; NH, non-Hispanic; OR, odds ratio; ref, referent; Q, quartile.

Table 2.7. Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of obesity at time 2 as a function of continuous change in neighborhood greenness (NDVI) in 299,369 mothers did not move between time 1 and time 2, controlling for obesity at time 1 and individual-level covariates.

Parameter	OR	95% CI
Change in NDVI	0.79	(0.69, 0.90)
Obesity (time 1)	49.6	(48.2, 51.0)
Insurance		
Private (ref)		
Public	1.37	(1.33, 1.42)
Other	1.04	(0.99, 1.10)
Parity		
2 births	0.82	(0.80, 0.85)
≥ 3 births (ref)		
Maternal age (years)		
<20	0.71	(0.66, 0.77)
20-24 (ref)		
25-29	0.88	(0.85, 0.92)
30-34	0.72	(0.69, 0.75)
35-39	0.68	(0.66, 0.71)
≥ 40	0.68	(0.64, 0.73)
Education		
Less than HS	1.23	(1.18, 1.28)
High school	1.34	(1.30, 1.38)
Some college (ref)		

Abbreviations: CI, confidence interval; HS, high school; NDVI, Normalized Difference Vegetation Index; OR, odds ratio; ref, referent

Table 2.8. Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of upward green mobility (vs. lateral or downward green mobility) as a function of time 1 health and socio-demographic characteristics in 253,549 mothers who moved between time 1 and time 2.

Parameter	OR	95% CI	
Obesity	0.98	(0.96,	1.01)
NH white (ref)			
NH black	0.76	(0.73,	0.79)
Asian	0.97	(0.94,	1.00)
Hispanic	0.86	(0.84,	0.88)
Insurance			
Private (ref)			
Public	0.93	(0.91,	0.95)
Other	0.81	(0.78,	0.85)
Parity			
1 birth	1.08	(1.04,	1.11)
2 births	1.02	(0.98,	1.06)
≥ 3 births (ref)			
Maternal age (years)			
<20	1.02	(0.99,	1.05)
20-24 (ref)			
25-29	1.05	(1.02,	1.07)
30-34	1.11	(1.08,	1.14)
35-39	1.12	(1.08,	1.17)
≥ 40	1.07	(0.94,	1.21)
Education			
Less than HS	0.91	(0.88,	0.93)
High school	0.92	(0.89,	0.94)
Some college (ref)			

Abbreviations: CI, confidence interval; HS, high school; NH, non-Hispanic; OR, odds ratio; ref, referent

Table 2.9. Generalized Linear Mixed Model: Odds ratios (OR) and 95% confidence intervals (CI) predicting the probability of obesity at time 2 as a function of continuous change in NDVI (Normalized Difference Vegetation Index), controlling for maternal obesity at time 1, time-varying covariates, and between-neighborhood variation in obesity.

		Model 9
Parameter	OR	95% CI
Change in NDVI	0.82	(0.72, 0.95)
Sample		full
Mother fixed effects		yes
Random intercepts		yes
Covariates included (yes/no)		
Individual sociodemographic[a]		yes
Neighborhood disadvantage[b]		yes
Neighborhood mobility[c]		no

Abbreviations: CI, confidence interval; NDVI, Normalized Difference Vegetation Index; OR, odds ratio.
[a] Model controlled for age, insurance provider, educational attainment at time 2.
[b] Model controlled for neighborhood disadvantage at time 2; model omitted neighborhood disadvantage at time 1 because of collinearity.
[c] Model omitted neighborhood mobility because of collinearity.

Figure 2.1. Quartiles of neighborhood greenness in urban census tracts in Los Angeles, California, 2010.

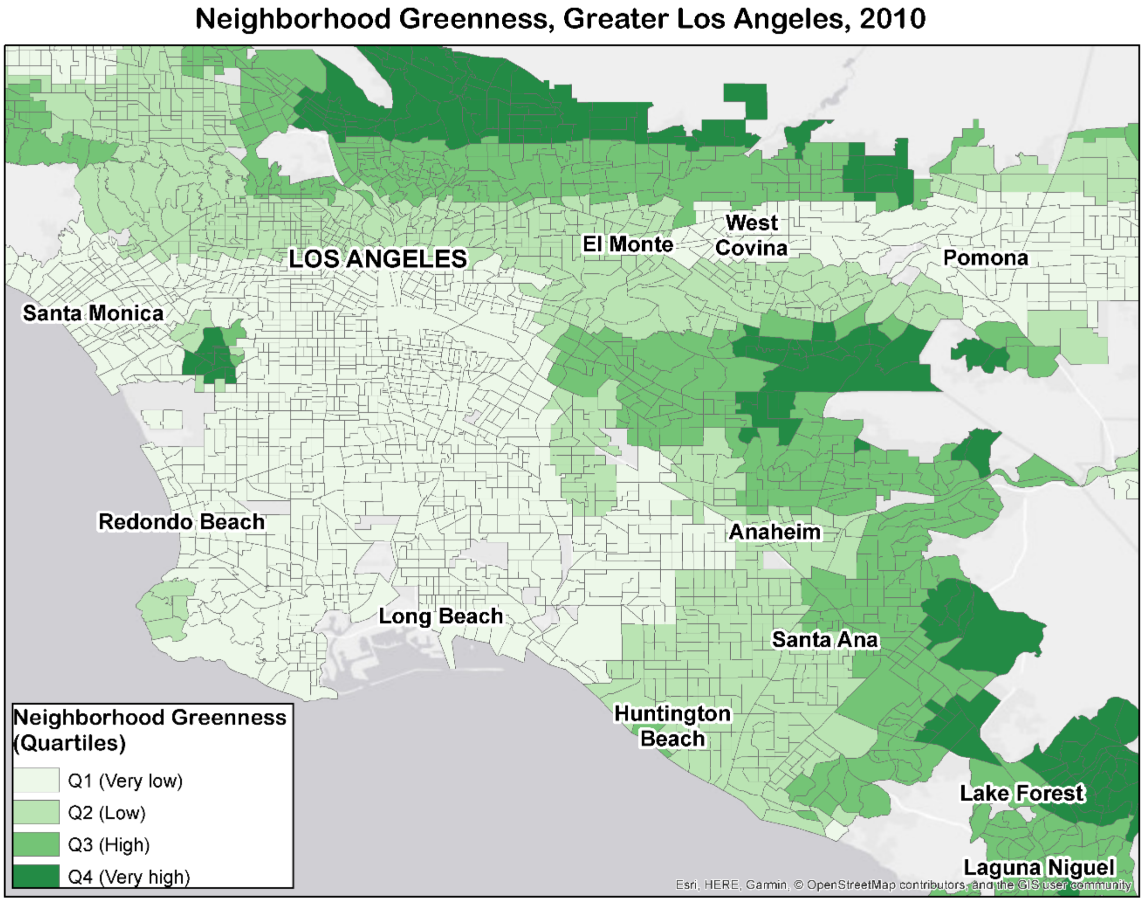
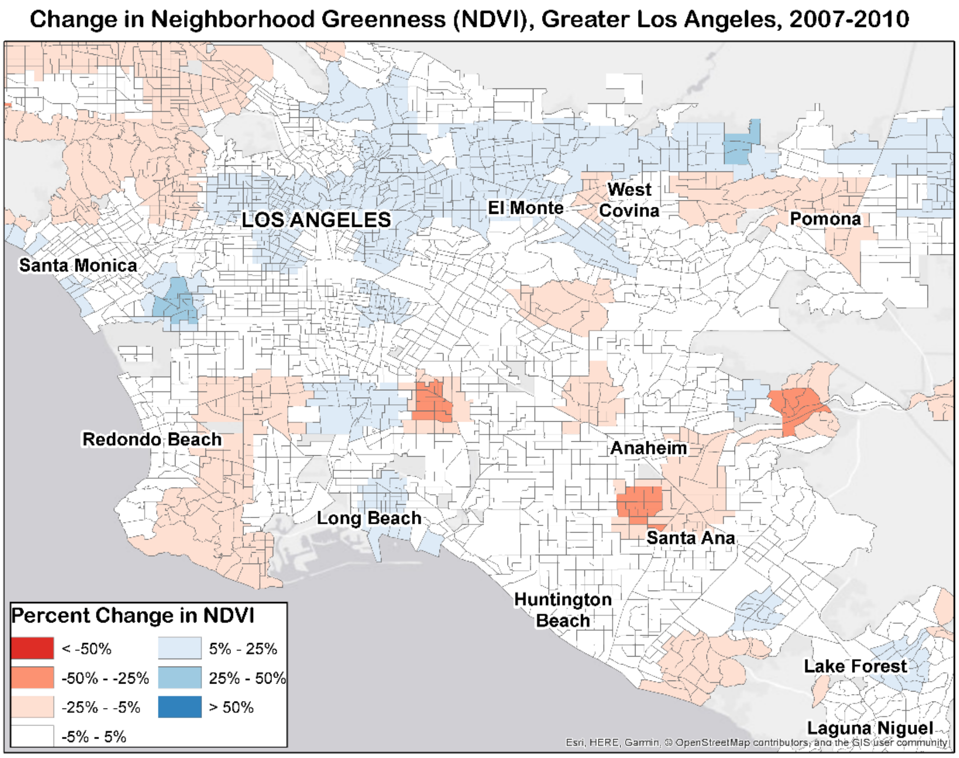
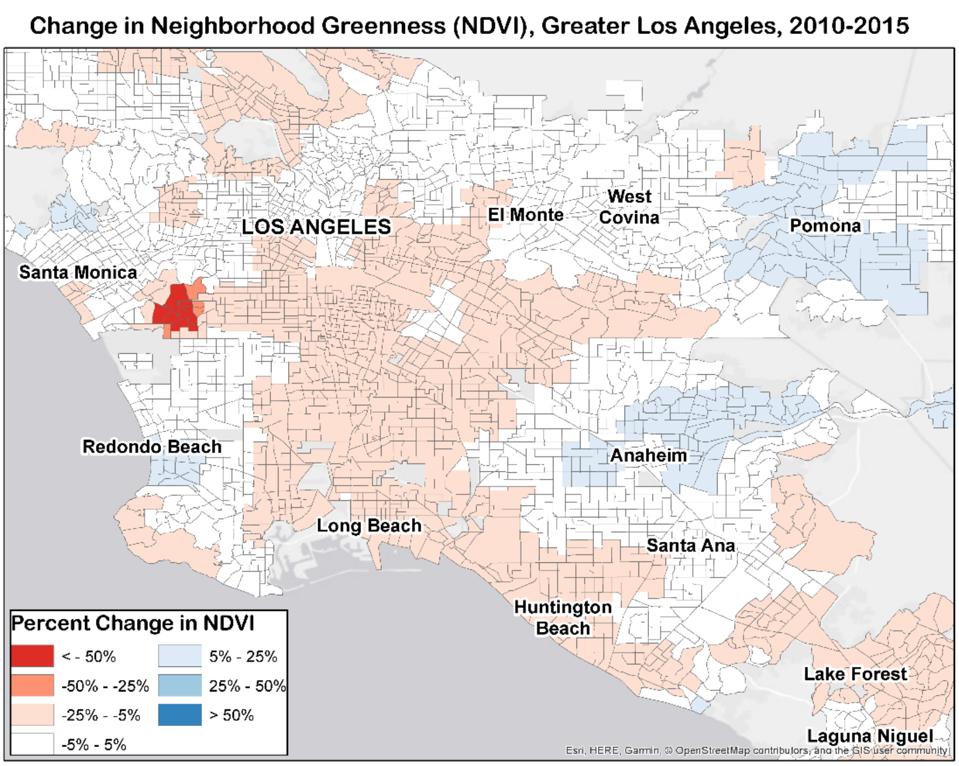


Figure 2.2. Percent change in neighborhood greenness between (A) 2007 and 2010, (B) 2010 and 2015, and (C) 2007 and 2015

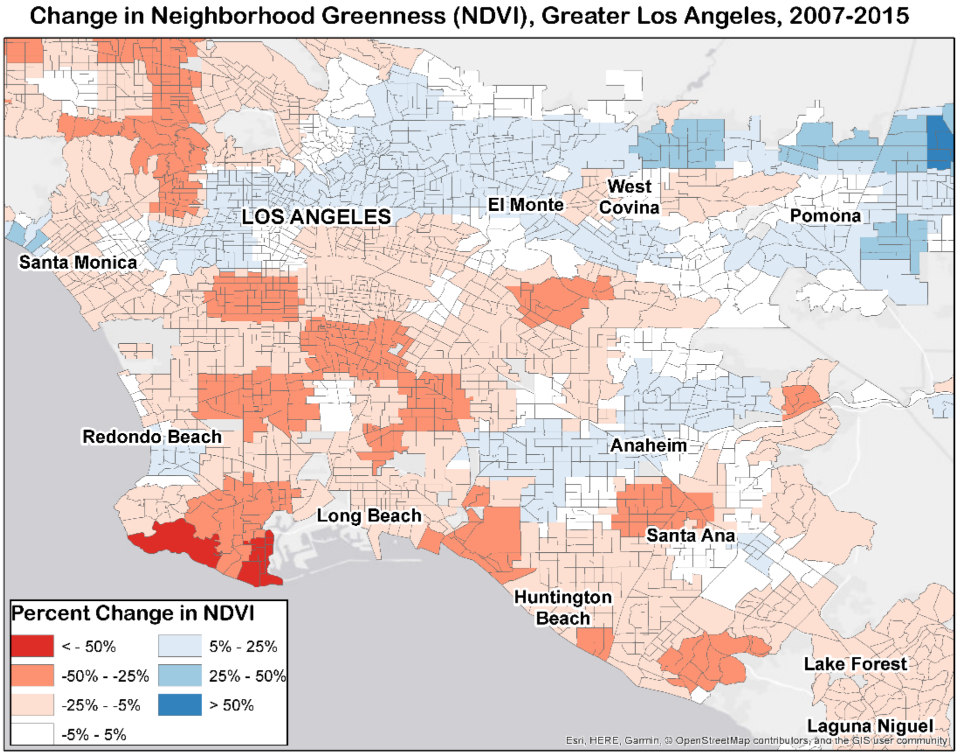
A.



B.



C.



Change in Neighborhood Greenness (NDVI), Greater Los Angeles, 2007-2015
LOS ANGELES
El Monte
West Covina
Pomona
Santa Monica
Redondo Beach
Anaheim
Long Beach
Santa Ana
Huntington Beach
Lake Forest
Laguna Niguel
Percent Change in NDVI
< - 50%
-50% - -25%
-25% - -5%
-5% - 5%
5% - 25%
25% - 50%
> 50%
Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

CHAPTER 3

Changes in residential greenness and adverse birth outcomes: Differences by maternal race/ethnicity

In the US, the incidence of adverse birth outcomes including preterm birth (PTB) and low birthweight (LBW) exceed those of all other high-income countries (OECD, 2020). PTB and LBW, defined as delivery at less than 37 weeks of gestation and birthweight of less than 2,500 grams, respectively, impose substantial hospital-based obstetric costs, impair infant development, and increase infant mortality risk. In addition, survivors of PTB and LBW show reduced earnings and educational attainment into adulthood (Behrman & Butler, 2007; Goldenberg et al., 2008; Moster et al., 2008). Given the deleterious lifecourse sequalae and financial burdens associated with PTB and LBW, these adverse birth outcomes command considerable attention from scholars and policy makers.

Despite recent clinical and public health interventions, PTB and LBW remain consistently high. Racial-ethnic minorities exhibit substantially greater risk of adverse birth outcomes; non-Hispanic (NH) Black mothers, in particular, remain more than twice as likely to deliver a preterm or low weight birth than NH white mothers (Martin et al., 2017; Ratnasiri et al., 2018). Individual sociodemographic and behavioral characteristics, however, do not fully explain this persistent disparity (David & Collins, 1997).

Research on PTB and LBW indicates complex etiologies that likely involve interactions among biological, behavioral, and environmental factors (Butler & Behrman, 2007; Goldenberg et al., 2008). Disadvantaged neighborhoods, for example, may contribute to increased risk of, and persistent disparities in, birth outcomes owing to harmful environmental exposures (e.g., air pollution) and limited access to health-promoting resources (e.g., prenatal care facilities) (Ncube et al., 2016). However, interventions that encourage upward residential mobility (i.e., moves to less disadvantaged neighborhoods) are expensive and show inconsistent evidence of health benefits (Oakes et al., 2015; Osypuk et al., 2012; Ludwig et al., 2011). Recently, researchers have explored the benefits of increasing greenspace in the residential environment as a potential intervention to improve maternal and perinatal health. This possibility has gained interest in the scholarly community given that greenspaces (1) show well-documented benefits for myriad physical and mental health outcomes (James et al., 2015), and (2) appear more feasible and less expensive to modify relative to other neighborhood-level exposures (WHO, 2017).

Neighborhood Greenspace and Perinatal Health

Neighborhood greenspace may improve perinatal health and reduce racial/ethnic disparities in adverse birth outcomes through several psychosocial, behavioral, and environmental pathways. At the individual level, 'restorative environments' theories – including Attention Restoration Theory (ART; Kaplan, 1995) and Stress Recovery Theory (SRT; Ulrich, 1991) – expound on the psychologically-restorative benefits of natural environments. These theories, while proposing different biological and psychological mechanisms, agree that, under antecedent conditions of stress or cognitive fatigue, natural environments can promote psycho-physiological recovery.

Substantial laboratory-based and quasi-experimental research guided by these theories supports that exposure to greenspace reduces physiological and psychosocial stress (Bowler et al., 2010; Hartig & Kahn, 2016). A recent review of 43 non-laboratory studies that use 'real time' anthropometric measures of stress (e.g., derived from saliva, blood, and EEG) finds consistent evidence that spending time outdoors (e.g., nature viewing, walking, gardening) precedes salutary changes in heart rate and blood pressure, as well as self-reported mood (Kondo et al., 2018). Observational studies that assess stress biomarkers (e.g., cortisol) as a function of longer-term exposure to residential environments also support the notion that nearby greenspace serves an important restorative function. For example, Roe et al. (2013) find that, among residents living in disadvantaged urban neighborhoods in the UK, higher levels of residential greenspace vary with steeper diurnal cortisol decline — an indicator of a healthy stress response.

This evidence holds relevance for research on perinatal health as prenatal maternal stress may increase the risk of a low weight and/or preterm birth (see review by Beydoun & Saftlas, 2008). A broad range of individual and ecological stressors appear to affect intrauterine growth and the timing of parturition, including experiences of perceived racism (Dominguez et al., 2008), presidential elections (Gemmill et al., 2019), and terrorist attacks (Bruckner et al., 2019). The literature has not converged on the type, timing, or 'dose' of a stressor sufficient to induce perinatal sequelae. However, findings from diverse studies indicate that, in general, stress triggers a physiological response along the maternal hypothalamic–pituitary–adrenal (HPA) axis. This disruption may result in elevated intrauterine and fetal cortisol concentrations and/or perturb normal placental function (Beijers et al., 2014). Neighborhood greenspace, as a setting for restorative experiences, may mitigate the extent to which exposure to stressors adversely affects the course of pregnancy — i.e., by operating as a 'stress buffer' (Wells & Evans, 2003).

Natural environments may also confer ecological benefits, or 'ecosystem services,' that improve perinatal health (Hartig et al., 2014). Much work on this topic focuses on associations and interactions between residential greenspace and air pollution among pregnant women (e.g., Markevych et al., 2017). Studies find stronger inverse associations between greenspace and PTB among women with greater air pollution exposure during pregnancy (Sun et al., 2020) and show that reductions in fine particulate matter mediate the association between greenspace and LBW (Laurent et al., 2019). In addition, residential greenspace may encourage behaviors (e.g., physical activity) and bolster social connections that promote maternal health more broadly. For example, mothers in California who experienced increases in residential greenspace between pregnancies show lower risk of maternal obesity, which may in turn improve perinatal outcomes (Gailey et al., 2021).

Epidemiological research builds on theoretical and empirical work demonstrating these and other potential pathways by which greenspace may improve perinatal health. Growing studies examine whether greenness in a mother's prenatal environment — typically measured using vegetation indices (e.g., Normalized Difference Vegetation Index [NDVI]) derived from satellite images of the earth's surface — correlates with more favorable birth outcomes (see Banay et al., 2017; Dzhambov, Dimitrova, & Dimitrakova, 2014 for review). Although this work provides some evidence of perinatal health benefits (e.g., Laurent et al., 2013; Agay-Shay et al., 2019), findings on outcomes associated with residential greenness remain mixed.

A recent review of this literature observes evidence of higher birthweight in greener neighborhoods, but null relations between greenness and gestational length and PTB (Banay et al., 2017). Casey et al. (2016), conversely, find an inverse association between residential greenness and PTB, but null relations with birthweight in Pennsylvania cities. Other studies assessing multiple outcomes (e.g., birthweight, gestational length) find no or weak evidence that living in greener areas improves perinatal health (Margerison et al., 2020).

Residential Selection

Most studies examining perinatal outcomes associated with neighborhood greenness assess cross-sectional relations at birth, which limits causal inference and may lead to inconsistent findings (Banay et al., 2017). In a study using birth data from two cities (Austin, TX and Portland, OR), for example, Cusack et al. (2017) observed positive unadjusted associations between greenness and birthweight but find null or negative relations after controlling for maternal race/ethnicity and other individual-level covariates. Changes in inference across unadjusted and 'fully-adjusted' models highlight the susceptibility of cross-sectional designs to bias induced by unmeasured (or poorly measured) characteristics of mothers and their residential environments.

Residential selection, whereby healthier or higher socioeconomic position (SEP) mothers 'select' into greener neighborhoods, presents a plausible explanation for previously observed protective associations between neighborhood greenness and birth outcomes. Mothers with better health at baseline may move to places with more health-promoting resources, including parks and greenery. Individual attitudes and behavioral tendencies (e.g., a preference for outdoor physical activity) may drive neighborhood choices. In addition, socioeconomic factors that strongly correlate with both place and birth outcomes may indirectly result in a 'compositional' – rather than a 'contextual' – association with greenness (Glass & Bilal, 2016).

To this end, Margerison et al. (2020) tested whether maternal characteristics associated with both place of residence and birth outcomes may explain protective associations. Consistent with prior work, results of cross-sectional analyses indicated that residential greenness varies with lower risk of PTB and increased birthweight, adjusting for individual- and neighborhood-level covariates including race/ethnicity and SEP. The Authors then conducted a longitudinal 'within-mother' analysis to further control for time-invariant maternal characteristics. Results no longer rejected the null, which supports that unmeasured confounders may explain their (and other researchers') findings of cross-sectional associations between greenness and birth outcomes. This study advances the argument that differential selection into residential area by mothers with different tendencies to deliver a low weight and/or preterm birth at baseline represents a key threat to validity in cross-sectional designs.

Effect Modification

An alternate explanation for equivocal findings in the literature involves individual and neighborhood characteristics moderating (rather than confounding) associations between residential greenness and birth outcomes. Race/ethnicity, SEP, and perceived neighborhood safety, to name a few, may influence one's ability or desire to access and utilize greenspace for health benefits. If so, heterogeneous populations and different area-level composition across studies may account for inconsistent findings (Cusack et al., 2017).

For instance, several studies find that education level modifies the association between residential greenness and birth outcomes. Less educated mothers generally show stronger protective associations (Dadvand et al., 2012; Maas et al., 2009; Markevych et al., 2014). For example, a study in a Spanish cohort finds null relations between greenness and birth outcomes overall, but a protective association among mothers in the lowest education stratum (Dadvand et al., 2012). Research demonstrating effect modification by education and other socioeconomic metrics often cite that lower SEP populations (1) spend more time near their residences and thus receive greater benefits from greenness surrounding the home, and (2) have poorer health status and greater exposure to environmental hazards at baseline, which higher levels of residential greenness may mitigate (Maas et al., 2008).

Race/Ethnicity

Different levels of exposure to environmental and social stressors among non-Hispanic (NH) white and NH Black mothers in the US also warrants further investigation. As outlined above, prenatal stress and exposure to environmental hazards during pregnancy elevates risk for LBW and PTB. Substantial research documents higher levels of maternal stress (Rosenthal & Lobel, 2011) and ambient exposure to air pollution (Gwynn & Thurston, 2001; Theyamballi et al., 2020) among NH Black mothers, likely contributing to persistent racial disparities in birth outcomes (Giscombé & Lobel, 2005; Benmarhnia et al., 2017). Given evidence that residential greenness reduces stress (Kondo et al., 2018) and air pollution exposure (Lee et al., 2021; Laurent et al., 2019; Sun et al., 2020), this work suggests the hypothesis that residential greenness confers greater benefits to NH Black, compared to NH white, mothers.

At least one study assesses whether the relation between residential greenness and birth outcomes varies by race/ethnicity. Using cross-sectional data in the UK, Dadvand et al. (2014) find that higher levels of residential greenness vary positively with birthweight for mothers of White British, but not Pakistani, origins. However, the extent to which these findings generalize to births among NH white and NH Black mothers in the US remains unclear.

Black communities in the US face unique challenges, including neighborhood-level inequalities imposed by historical planning and zoning practices that unevenly distribute environmental hazards (Morello-Frosch et al., 2011; Maantay, 2001). Other structural disadvantages and experiences of discrimination contribute to heightened stress among Black populations, exacerbating susceptibility to environmental risks (Gee & Payne-Sturges, 2004). Differential exposure to social and environmental stressors may influence responses to residential greenness among NH Black mothers compared to less vulnerable populations. Additionally, researchers point to several important national differences (e.g., 'climate, land use, population density, and physical activity patterns') that may limit the generalizability of findings on nature and health in the UK to the US, and vice versa (Benton et al., 2021, p. 7). Lastly, as demonstrated by Margerison et al. (2020), key unobserved maternal characteristics may strongly bias cross-sectional studies of place-based disparities in birth outcomes.

Current Study & Hypotheses

This study examines racial-ethnic differences in longitudinal associations between residential greenness and birth outcomes, including birthweight and PTB, in the context of the US (California) between 2005 and 2015. Consistent with previous literature, I use several analytic strategies including longitudinal maternal fixed effects, or 'within-mother' analyses, to investigate potential unmeasured confounders (Margerison et al., 2020; Cusack et al., 2017). I also stratify analyses by maternal race/ethnicity to examine effect modification (Dadvand et al., 2014).

Building on recent longitudinal studies of residential greenness (Margerison et al., 2020; Gailey et al., 2021), I focus on mothers who remain in the same neighborhood across births, based on the logic that within-neighborhood changes in greenness more closely replicate a natural experiment or intervention. Changes in income, employment, or marital status, for example, may influence a mother's decision to move between births and her risk of adverse birth outcomes, potentially confounding relations with residential greenness.

I hypothesize that, in cross-sectional analyses that adjust for observed maternal and neighborhood characteristics, residential greenness will correspond with higher birthweight and lower odds of PTB among NH white and NH Black mothers. However, I predict that maternal fixed effects analyses, which further control for unobserved time-invariant characteristics of mothers, will show salutary effects of greenness on births to NH Black mothers alone. Moreover, I expect results of maternal fixed effects analyses to hold for mothers who do not move between births, such that within-neighborhood increases in residential greenness (i.e., mimicking a greenness intervention) will precede higher birthweight and lower odds of PTB among NH Black mothers.

Methods

Variables and Data

I retrieved data on all live births in California between January 2005 and December 2015 from the California Department of Public Health (CDPH) Birth Cohort Files (BCF). The BCF contains data recorded from the US Standard Certificate of Birth, including maternal and infant health and demographic characteristics, for more than 99.99% of births in California. Importantly, the BCF also includes information on mother's residential address at the time of birth, which I geocoded and linked to neighborhood-level data (described in detail in Chapter 1). CDPH records the race and ethnicity of the mother, which I used to classify into the following categories, consistent with the literature: non-Hispanic (NH) Black, NH white, Hispanic, Asian, and other. The State of California and the University of California, Irvine approved the study (IRB protocol approval # 13-06-1251 and 2013-9716, respectively).

Sibling Linkage Strategy

The BCF arrays data at the infant level and does not include unique maternal identifiers. To identify live births to the same mother, I used Link Plus (version 3.0), an open-source probabilistic record linkage program developed by the Division of Cancer Prevention within the Centers for Disease Control and Prevention (CDC). Details of the sibling linkage strategy appear in Chapter 2 (pp. 28-30).

The California BCF for years 2005 to 2015 includes records for 5,814,502 live births. I first excluded records of non-singleton birth events given that multiple births interfere with the sibling linkage process (n=185,930). I also excluded birth records missing data on mother's date of birth (n=2,183), last name (n=24,502), and first name (2,934) as I required this information to match siblings delivered by the same mother. The sibling linkage process resulted in a dataset with 1,340,676 mothers with at least two consecutive live births in California between 2005 and 2015.

Geocoding

The California birth files include data on mother's address, zip code, and city of residence. I geocoded maternal residential addresses at the time of each birth (i.e., for each sibling) to derive latitude and longitude point coordinates using ArcGIS software version 10.4 (Redlands, California). I located addresses using a 2013 street directory and joined point coordinates with census tracts, a proxy for neighborhoods, based on 2010 US Census geography. I excluded sibling pairs if the maternal residential address provided in one or more of the birth records did not reach a minimum location match score of 80%, or with unknown, missing, rural, or non-California census tracts (n=97,276). This process yielded an analytic sample of 922,263 mothers with at least two consecutive live births, and who lived in urban census tracts in California, from 2005 to 2015.

Variables

Movers vs. Stayers. Within this sample, I defined movers as mothers whose census tract changed between her first and second birth (n=433,079); stayers remained in the same census tract across births (n=489,184), although they could have moved within the tract.

Neighborhood Greenness*.* I retrieved neighborhood greenness from the NOAA Climate Data Record (CDR) Normalized Difference Vegetation Index (NDVI) remote sensing product. The NDVI CDR measures and summarizes surface vegetation activity across the globe and enjoys widespread use in epidemiological studies (Bell et al., 2008; Hystad et al., 2014; Rhew et al., 2011; Gailey et al., 2021). Details of the neighborhood greenness measure appear in Chapter 1 (p. 32)

Birth Outcomes. Primary outcomes include preterm birth (PTB), defined as birth at less than 37 weeks of gestation, and birthweight in grams. These data are recorded and retrieved from the US Standard Certificate of Birth.

Neighborhood Disadvantage. I merged individual-level data and measures of neighborhood greenness with a census tract-level measure of neighborhood disadvantage. I, consistent with past work, calculated an index of neighborhood disadvantage using six standardized variables retrieved from the 2010 U.S. Decennial Census: the proportion of households with income <\$15,000, the proportion of households with income ≥\$50,000 (reverse coded), the proportion of families in poverty, the proportion of households receiving public assistance, the total unemployment rate, and the proportion of vacant housing units (Cronbach's alpha = .92) (King et al., 2011).

Analytic Approach

I estimated associations between residential greenness and birth outcomes, overall and by race/ethnicity, using two primary approaches. I initially performed cross-sectional analyses to examine relations between residential greenness and birthweight (and, as a secondary outcome, PTB). Next, I leveraged longitudinal data on a mother's first and second births and used a maternal fixed effects, or 'within-mother,' approach to estimate relations between changes in greenness and birth outcomes.

In contrast to cross-sectional analyses, maternal fixed effects models include a mother-specific indicator variable to control for time-invariant characteristics of the mother. Analyses estimate the influence of a change in residential greenness on birth outcomes using a (within-mother) counterfactual — that is, the birth outcome of a sibling born under different conditions of greenness in the residential environment. By comparing births within the same mother, this approach controls for unobserved confounders that remain relatively stable over time. For example, within-mother analyses control for characteristics of the mother that may influence both where she lives and her birth outcomes, thus minimizing the risk of bias due to residential selection.

For all models, I first estimated overall associations between neighborhood greenness and birth outcomes in the full analytic sample of mothers (i.e., across racial/ethnic groups) with at least two births in California between 2005 and 2015. I then stratified analyses by race/ethnicity to assess greenness/birth outcome relations separately for NH white and NH Black mothers. I used linear regression models to predict birthweight (in grams) and logistic regression to estimate the odds of PTB.

Cross-Sectional Analyses

Model 1 assessed the unadjusted association between residential greenness and birth outcomes at time 1 (i.e., sibling 1). Model 2 controlled for individual- and neighborhood-level covariates that could affect both residential greenness and birth outcomes, including year of birth (to control for secular trends), maternal age, education, parity, insurance status, and neighborhood disadvantage. Model 3 used a pooled cross-sectional time series approach to assess relations between residential greenness and birth outcomes at time 1 and time 2. Given that these analyses include multiple births to the same mother, I clustered standard errors by mother and, consistent with Model 2, adjusted for year of birth and individual- and neighborhood-level covariates.

Within-Mother Analyses

All fixed effects within-mother analyses included a mother-specific indicator variable to control for time-invariant maternal characteristics. Model 4 examined the within-mother association between changes in residential greenness and birth outcomes for all mothers with at least two consecutive live births. Models 5 and 6 restricted analyses to mothers who remained in the same neighborhood (i.e., 'stayers'), and mothers who moved between births (i.e., 'movers'), respectively.

Results

Table 3.1A shows descriptive statistics for mothers and singleton live births (at time 2) in California between 2005 and 2015. The full analytic 'within-mother' sample (left column) displays characteristics of all mothers with at least two consecutive births over the study period (n=922,263); the 'stayers only' sample (right column) shows characteristics of mothers within the full sample who remained in the same neighborhood across births. Both the full within-mother sample and the restricted stayers sample include mothers from racially and economically diverse backgrounds. Most mothers in the full sample (Table 3.1A, left column) identified as Hispanic (50.28%) or NH white (26.81%), attained at least some college education (52.18%), and had private health insurance (49.88%) at the time of their second birth. A higher proportion of mothers who stayed in the same neighborhood across births reported at least some college education and had private health insurance (Table 3.1A, right column). This result coheres with the notion that higher SEP groups tend to move less frequently.

Tables 3.1B and 3.1C show characteristics of NH white (n=247,285) and NH Black (n=54,995) mothers and their births at time 2. Compared to NH white mothers (Table 3.1B), a higher proportion of NH Black mothers (Table 3.1C) reported having public health insurance and attained less than a high school education. Infants born to NH Black mothers were substantially lighter (mean birthweight = 3,227.65 grams) and spent less time in gestation (mean GA = 272.54 days) on average than infants born to NH white mothers (mean birthweight = 3,472.46 grams, mean GA = 275.60 days). In addition, NH Black mothers lived in neighborhoods with greater disadvantage and less greenness than NH white mothers.

Table 3.2 shows the distribution of neighborhood greenness, categorized into quartiles, at time 1 (first birth) and time 2 (second birth) in the full analytic sample (Table 3.2A) and, separately, for NH white (Table 3.2B) and NH Black (Table 3.2C) mothers. At the time of both births, more NH white mothers lived in neighborhoods with high levels of greenness, and fewer lived in neighborhoods with low levels of greenness, than NH Black mothers. For example, approximately 17% of NH white mothers lived in neighborhoods with very low (quartile [Q] 1) greenness at time 1, compared to more than 38% of NH Black mothers. Across racial/ethnic groups, a slightly higher proportion of mothers lived in neighborhoods with high (Q3) and very high (Q4) levels of greenness at time 2 compared to time 1, indicating that more mothers moved to greener, rather than less green, neighborhoods over time.

Table 3.3 also shows small increases in neighborhood greenness between births, on average, among the full analytic sample (mean change = 0.01) and NH Black mothers (mean change = 0.03). NH white mothers, conversely, show small decreases in neighborhood greenness (mean change = -0.01). Relatively large standard deviations in both the within-mother and stayer samples suggest considerable variation in the change in greenness that mothers experienced between births.

Cross-Sectional Analyses

Table 3.4 shows results of cross-sectional analyses (Models 1-3) predicting birthweight as a function of residential greenness in the full analytic sample and NH white and NH Black mothers. Across all cross-sectional models, I find positive associations between residential greenness and birthweight in all race/ethnicities but observe stronger associations among NH Black mothers. Model 1 (not adjusted for covariates) indicates that a 1-unit increase in NDVI corresponds with a 120.33-gram increase in birthweight among births to NH Black mothers, relative to a 59.09-gram increase in birthweight to NH white mothers. Adjusting for individual- and neighborhood-level covariates (Model 2) attenuates point estimates, but the direction of the inference does not change. Model 3, which estimates cross-sectional relations between residential greenness and birth outcomes at time 1 and time 2, also shows positive greenness/birthweight associations (in grams) for NH Black (coef. = 92.60, CI: 67.68, 117.51) and NH white (coef. = 68.08, CI: 55.61, 81.56) mothers.

Within-Mother Analyses

Maternal fixed effects analyses (Table 3.4) comparing birth outcomes within the same mother (i.e., with different levels of exposure to greenness across births) indicate that the positive greenness/birthweight result holds only for NH Black mothers (coef. = 74.59, CI: 23.48, 127.50) (Model 4). Results of within-mother analyses in mothers who remain in the same neighborhood

(Model 5) and who move between births (Model 6) also show that increases in greenness correspond with increases in birthweight among NH Black, but not NH white, mothers (see summary of results in Figure 3.1).

Results on relations between neighborhood greenness and PTB cannot reject the null. Cross-sectional and within-mother analyses in the full analytic sample, NH white, and NH Black mothers show no statistically detectable associations.

Discussion

Growing epidemiologic work examines whether greenness in a mother's residential environment during pregnancy reduces her risk of a low weight and/or preterm birth (Banay et al., 2017; Dzhambov et al., 2014). Findings do not converge, with some studies showing more favorable birth outcomes among mothers residing in greener neighborhoods (Laurent et al., 2013; Agay-Shay et al., 2019), and others showing mixed (Casey et al., 2016) or null (Margerison et al., 2021) results. Recently, researchers have pointed to potential sources of bias in cross-sectional work (e.g., residential selection) and cross-study population heterogeneity (e.g., differences by maternal sociodemographic characteristics) as plausible explanations for inconsistent findings (Margerison et al., 2021; Cusack et al., 2017).

I contribute to this literature by leveraging longitudinal data to examine, by maternal race/ethnicity, whether changes in residential greenness vary with improved birth outcomes among mothers in California with at least two births between 2005 and 2015 (n=922,263). Results of cross-sectional analyses show positive associations between residential greenness and birthweight for NH white and NH Black mothers. However, maternal fixed effects analyses, which provide more robust control for unobserved confounders, indicate that increases in residential greenness between births correspond with greater birthweight only for NH Black mothers. Moreover, this result holds when restricting the analysis to NH Black mothers who remain in the same neighborhood across births. This finding, in particular, holds relevance for translational science as it suggests that interventions that improve upon existing levels of greenness in the residential environment may reduce racial disparities in birthweight.

Contrary to my hypothesis, results on associations between neighborhood greenness and PTB cannot reject the null. Findings indicate that increases in greenness may affect intrauterine growth but not timing of parturition, cohering with some past studies (Batay et al., 2017). Lower maternal stress offers one potential pathway through which greater exposure to greenness results in perinatal improvements. A recent meta-analysis finds that birthweight, more so than preterm birth, responds adversely to maternal stress *in utero* (Lima et al., 2018). Findings of this study suggest that birthweight may also benefit to a greater extent from the stress-buffering effects of greenness. Additional research which examines physiological measures in response to greenness among pregnant women may improve understanding of this proposed mechanism.

Effect Modification

This study advances a small but growing body of research examining heterogeneity in relations between neighborhood greenness and birth outcomes by maternal sociodemographic characteristics (Dadvand et al., 2012a; Dadvand et al., 2012b; Maas et al., 2009; Markevych et al., 2014; Ebisu, Holford, & Bell, 2016). Prior work finds that the benefits of greenness concentrate among mothers with lower education and income levels, consistent with studies on greenness, health, and SEP more broadly. Associations between residential greenness and other health outcomes including cardiovascular disease mortality (Mitchell & Popham, 2008) and self-rated health (van den Berg et al., 2010), for example, also appear stronger (i.e., more protective) among lower SEP populations. Explanations include that, due to mobility constraints, individuals of lower SEP spend more time in direct living environments and consequently have greater exposure to, and receive more benefits from, residential greenness (Maas et al., 2008). Research also documents worse health among lower SEP populations (Davey Smith et al, 1994), creating greater opportunities for health improvement. These explanations, however, would benefit from additional empirical studies on time use, measurements of exposure to greenness, and health.

Given the substantial correlation between low SEP and minority race/ethnicity in the US (LaVeist, 2005), results of the current study, which show that NH Black but not NH white mothers benefit from increased residential greenness, may cohere with past work on SEP, greenness, and perinatal health. Descriptive statistics indicate that a higher proportion of NH Black mothers in the study sample attained less than a high school education and received public health insurance (mostly MediCAL), indicating lower SEP among this group compared to NH white mothers. It remains possible, therefore, that SEP (and not race, *per se*) partially explains differences in greenness/birthweight relations among NH white versus NH Black mothers. As such, reasons including disparities in mobility and health status at baseline may also pertain to the findings of this study.

Much less work has examined whether associations between residential greenness and birth outcomes differ by race/ethnicity. Two studies — one in Canada (Hystad et al., 2014) and one in the US (Ebisu et al., 2016) — find no evidence of effect modification by area- or individual-level race/ethnicity. At least one study in the UK has examined racial/ethnic differences in the association between residential greenness and birthweight, and finds, in contrast to this study, a positive association among white, but not ethnic minority (e.g., Pakistani) mothers (Dadvand et al., 2014).

Strengths and Limitations

The current study diverges from Dadvand et al. (2014) and other cross-sectional studies in several key ways. First, a principal strength of this analysis involves the use of longitudinal data and maternal fixed effects to control for time-invariant maternal characteristics that may confound greenness/birth outcome associations. Consistent with prior work (e.g., Dadvand et al., 2014), I initially find a strong positive association between greenness and birthweight among NH white, as well as NH Black, mothers in analyses that control only for observed maternal and neighborhood characteristics. However, the inclusion of a mother-specific indicator variable that further controls for time-invariant maternal characteristics ameliorates this association in NH white mothers. These findings indicate that residential selection (i.e., the process through which healthier women choose to live in greener neighborhoods) may result in a spurious association among white mothers in studies that cannot account for unmeasured confounders (Margerison et al., 2020).

Second, I restricted fixed effects analyses to mothers who did not move but for whom greenness changed within their neighborhoods. Findings cohere with results of the full within-mother analysis (i.e., including stayers and movers) in that NH Black but not NH white mothers who experienced positive changes in greenness between pregnancies exhibit increases in birthweight. The consistency of results across samples minimizes the likelihood that residential selection biases this relation. Future research that emulates random assignment of mothers to conditions of greenness (e.g., intervention evaluation studies; see Benton et al., 2021) should further refine and test the hypothesized causal effect of greenness on birth outcomes.

Another strength of this study includes the use of the California birth files for years 2005 to 2015 to provide a large and racially diverse sample of mothers. This sample was sufficient to permit theoretically motivated tests of Black-white differences in greenness/birth outcome associations. Importantly, the analytic sample included over 50,000 NH Black women, who, in the US, exhibit the highest rates of LBW and PTB compared to all other racial-ethnic groups. Well-documented risk factors for adverse birth outcomes including exposure to environmental hazards (e.g., air and noise pollution, poor water quality, and extreme heat) and heightened stress during pregnancy disproportionately affect NH Black women (Benmarhnia et al., 2017; Rosenthal & Lobel, 2011). Evidence of the unique risks affecting NH Black women in the US, taken together with findings of the current study, support that residential greenness may contribute to increased birthweight among NH Black mothers through the provision of ecosystem services and psychological restoration.

Limitations of this study include a lack of information on the mechanisms by which neighborhood greenness affects pregnancy. In addition to reducing stress and improving environmental conditions, research indicates that neighborhood greenness may increase physical activity and social contacts that contribute to maternal health more broadly (Hartig et al., 2014; Markevych et al., 2017). Given that the birth files do not contain behavioral or biomarker data, it remains unclear whether these mechanisms influenced the course of pregnancy among mothers in the analytic sample. Pathways underlying the observed greenness/birthweight result warrant further investigation. For example, studies that use ambulatory assessment methods to track behavioral and biological responses of pregnant women to greenspace in the context of everyday life may advance understanding of these processes. Additionally, studies that test psychological, behavioral, and environmental measures jointly can assess whether mechanisms operate independently or interactively to influence perinatal health.

Moreover, this study does not consider the processes through which greenness changes within a neighborhood over time. As discussed, residential selection may threaten internal validity in studies that rely on cross-sectional data or variation in residential greenness due to moving, as residents may 'select' into neighborhoods according to preexisting health or social factors (Margersion et al., 2020). By contrast, within-neighborhood change in greenness may serve as a plausibly exogenous exposure to the extent that vegetation levels fluctuate naturally. However, political decisions, concerted community action, or other non-natural sources of change that intervene on the environment may also threaten the validity of findings.

Wolch, Byrne, and Newell (2014) forward that urban greening — which often involves the transformation of remnant urban land to greenspaces in low-income 'park poor' neighborhoods — may create paradoxical effects. Urban greening may coincide with or set off rounds of gentrification, which increase property values and reduce housing opportunities. Greening projects, therefore, may displace the residents they intended to benefit. Within the context of this study, the process of 'green gentrification' (Gould & Lew, 2012) may lead to negative selection bias, as my analysis focuses only on residents who can afford to remain in transforming neighborhoods.

Other methodological limitations, including insufficient data on the timing of moves, amplified confounding due to the matched sibling design, and limits to external validity are discussed in Chapter 2. Another consideration regarding the external validity of findings includes that mothers who remain in the same neighborhood across births appear slightly older and of higher SEP than mothers who move. Findings on relations between within-neighborhood increases in greenness and birthweight may, therefore, pertain only to this sample, or generalize to older mothers of relative high SEP in the broader population.

Conclusion

Inconsistent findings on associations between neighborhood greenness and birthweight may derive from bias in cross-sectional study designs or heterogenous effects across mothers of different race/ethnicities. This study overcomes some limitations of previous work by using longitudinal data to analyze 'within-mother' associations between changes in greenness and birthweight among NH white and NH Black mothers. Results controlling for unmeasured maternal confounders show that birthweight increases among births to NH Black, but not NH white, mothers who experience positive changes in neighborhood greenness.

Results remain robust to a restricted sample of mothers who stay in the same neighborhood but experience within-neighborhood changes in greenness between births. Such changes more closely mimic, from a methodological perspective, a quasi-experimental design, and, from an applied perspective, a neighborhood-level intervention. Findings suggest that greening projects that target neighborhoods in which NH Black mothers live may reduce disparities in birthweight.

Tables & Figures

Table 3.1. Characteristics of California singleton births (time 2) among (A) all race/ethnicities, (B) non-Hispanic (NH) white, and (C) NH Black mothers.

(A) All race/ethnicity

	Within-mother (n=922,263)		Stayers (n=489,184)	
Maternal variables	n	%	n	%
Race / ethnicity				
NH white	247,285	26.81	143,213	29.28
NH Black	54,995	5.96	21,251	4.34
NH Asian	136,414	14.79	78,952	16.14
Hispanic	463,707	50.28	235,331	48.11
Other	19,862	2.15	10,437	2.13
Age (years)				
<20	28,333	3.07	13,643	2.79
20-24	175,054	18.98	77,050	15.75
25-29	246,437	26.72	117,967	24.12
30-34	274,108	29.72	155,361	31.76
35-40	162,806	17.65	101,951	20.84
≥ 40	35,525	3.85	23,212	4.75
Education				
Less than HS	185,772	20.14	89,698	18.34
High school	224,241	24.31	108,120	22.10
Some college	481,281	52.18	275,075	56.23
Other	30,969	3.36	1,6291	3.33
Insurance				
Private	460,069	49.88	271,534	55.51
Public (MediCAL)	411,178	44.58	192,095	39.27
Other	51,016	5.53	25,555	5.22
Birth variables	Mean	STD	Mean	STD
Birthweight (grams)	3,375.65	512.58	3,385.41	510.23
Gestational age (days)	274.27	12.83	274.30	12.74
Neighborhood variables	Mean	STD	Mean	STD
NDVI	0.52	0.13	0.52	0.13
Disadvantage	0.10	0.76	0.04	0.74

(B) NH white

	Within-mother (n=247,285)		Stayers (n=143,213)	
Maternal variables	n	%	n	%
Age (years)				
<20	1,998	0.81	834	0.58
20-24	24,542	9.92	9,821	6.86
25-29	58,411	23.62	29,248	20.42
30-34	89,406	36.16	54,699	38.19
35-40	59,006	23.86	39,021	27.25
≥ 40	13,922	5.63	9,590	6.70
Education				
Less than HS	9,592	3.88	3,880	2.71
High school	39,803	16.10	19,003	13.27
Some college	193,699	78.33	117,956	82.36
Other	4,191	1.69	2,374	1.66
Insurance				
Private	187,233	75.72	116,143	81.10
Public (MediCAL)	45,421	18.37	19,166	13.38
Other	14,631	5.92	7,904	5.52
Birth variables	Mean	STD	Mean	STD
Birthweight (grams)	3,472.46	497.12	3,479.72	494.21
Gestational age (days)	275.60	11.73	275.63	11.66
Neighborhood variables	Mean	STD	Mean	STD
NDVI	0.55	0.12	0.55	0.12
Disadvantage	-0.26	0.61	-0.30	0.56

(C) NH Black

	Within-mother (n=54,995)		Stayers (n=21,251)	
Maternal variables	n	%	n	%
Age (years)				
<20	2,399	4.36	920	4.33
20-24	15,708	28.56	5,251	24.71
25-29	16,705	30.38	5,849	27.52
30-34	12,397	22.54	5,216	24.54
35-40	6,251	11.37	3,157	14.86
≥ 40	1,535	2.79	858	4.04
Education				
Less than HS	8,087	14.70	2,653	12.48
High school	18,044	32.81	6,449	30.35
Some college	27,627	50.24	11,701	55.06
Other	1,237	2.25	448	2.11
Insurance				
Private	18,784	34.16	8745	41.15
Public (MediCAL)	31,465	57.21	10,599	49.88
Other	4,746	8.63	1,907	8.97
Birth variables	Mean	STD	Mean	STD
Birthweight (grams)	3,227.65	560.75	3,252.01	566.43
Gestational age (days)	272.54	15.15	272.61	15.25
Neighborhood variables	Mean	STD	Mean	STD
NDVI	0.50	0.15	0.49	0.15
Disadvantage	0.56	0.86	0.47	0.85

Abbreviations: HS, high school; NDVI, Normalized Difference Vegetation Index; NH, non-Hispanic; STD, standard deviation.

Table 3.2. Distribution (n, %) of neighborhood greenness (NDVI) at time 1 and time 2 among (A) all race/ethnicity, (B) non-Hispanic (NH) white, and (C) NH Black mothers.

(A) All race/ethnicity

	Time 1		Time 2	
	n	%	n	%
Q1 (very low)	244,562	26.52	240,209	26.05
Q2	233,163	25.28	230,866	25.03
Q3	230,618	25.01	232,158	25.17
Q4 (very high)	213,920	23.20	219,027	23.75

(B) NH white

	Time 1		Time 2	
	n	%	n	%
Q1 (very low)	41,222	16.68	41,754	16.89
Q2	63,307	25.62	60,617	24.51
Q3	74,124	30.00	75,821	30.66
Q4 (very high)	68,419	27.69	69,092	27.94

(C) NH Black

	Time 1		Time 2	
	n	%	n	%
Q1 (very low)	21,365	38.33	21,064	38.30
Q2	10,349	18.57	9,560	17.38
Q3	11,215	20.12	11,175	20.32
Q4 (very high)	12,804	22.97	13,196	23.99

Abbreviations: NDVI, Normalized Difference Vegetation Index; NH, non-Hispanic; Q, quartile.

Table 3.3. Mean change (STD) in neighborhood greenness between births in within-mother and stayer samples by maternal race/ethnicity.

	Within-mother		Stayers	
	Mean	STD	Mean	STD
All race/ethnicity	0.01	(0.10)	0.01	(0.09)
NH white	-0.01	(0.10)	-0.01	(0.10)
NH Black	0.03	(0.11)	0.02	(0.09)

Abbreviations: NH, non-Hispanic; STD, standard deviation.

Table 3.4. Multivariable-adjusted beta coefficients for birthweight in grams among singleton live births as a function of residential greenness, overall and by race/ethnicity, among mothers with at least two live births in California, 2005-2015.

Cross-sectional analyses

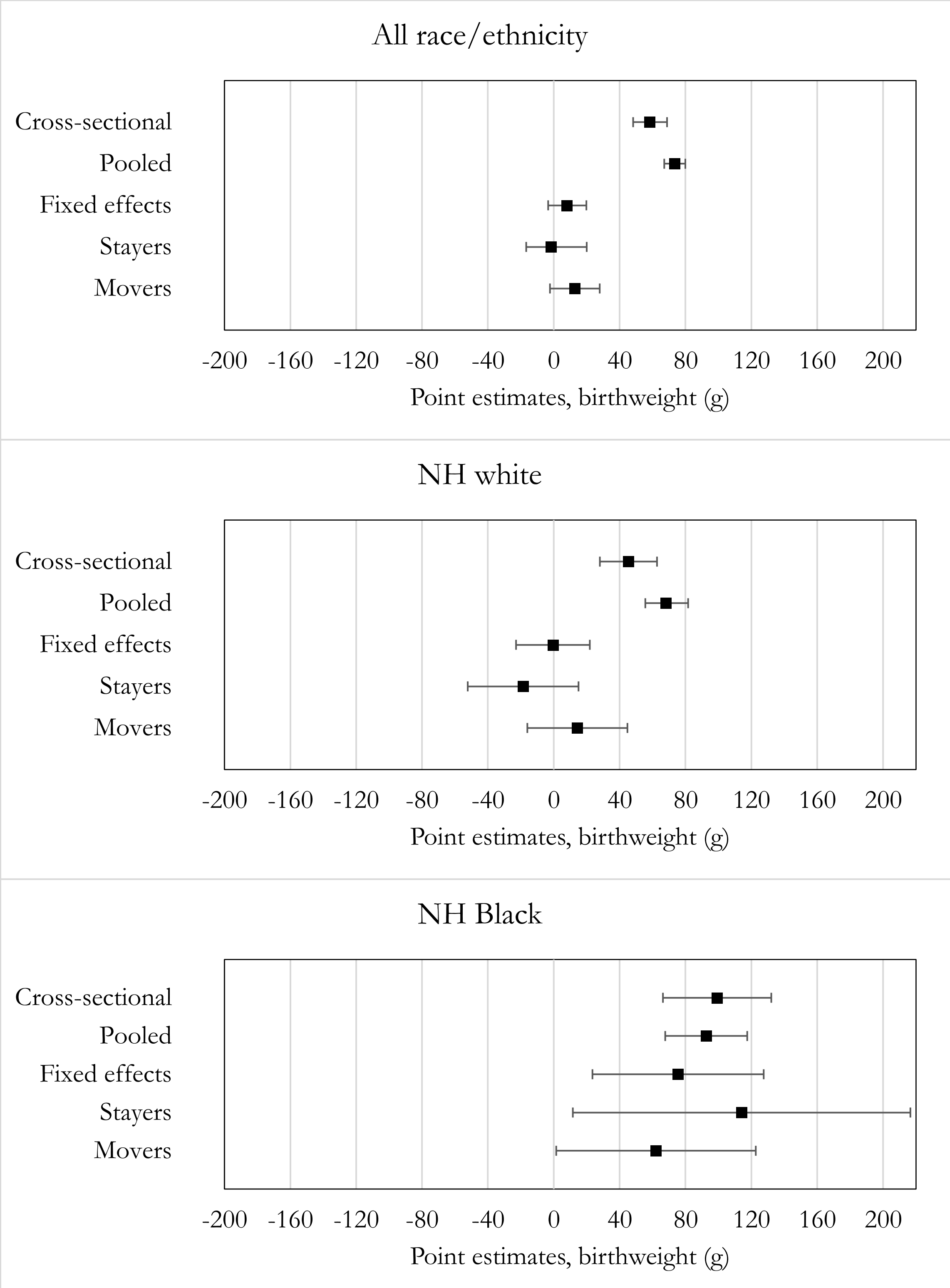
	Model 1			**Model 2**			**Model 3**		
	Coef.	CI		Coef.	CI		Coef.	CI	
Race/ethnicity									
All	97.39	(89.37,	105.40)	68.64	(60.32,	76.96)	73.47	(67.07,	79.86)
NH white	59.09	(42.81,	75.38)	52.62	(35.87,	69.37)	68.08	(55.61,	81.56)
NH Black	120.33	(88.63,	152.03)	97.18	(64.99,	129.38)	92.60	(67.68,	117.51)
Sample includes:									
Sibling 1 (time 1)	Yes			Yes			Yes		
Sibling 2 (time 2)	No			No			Yes		
Stayers	N/A			N/A			N/A		
Movers	N/A			N/A			N/A		
Adjusted for:									
Exposure year	No			Yes			Yes		
Maternal variables	No			Yes			Yes		
Tract variables	No			Yes			Yes		
Maternal fixed effects:	No			No			No		

Within-mother analyses

	Model 4		Model 5		Model 6	
	Coef.	CI	Coef.	CI	Coef.	CI
Race/ethnicity						
All	8.19	(-3.41, 19.81)	-1.63	(-16.74, 20.01)	12.80	(-2.30, 27.90)
NH white	-0.51	(-22.94, 21.91)	-18.60	(-52.25, 15.04)	14.35	(-16.04, 44.74)
NH Black	75.49	(23.48, 127.50)	114.07	(11.58, 216.58)	62.09	(1.50, 122.68)
Sample includes:						
Sibling 1 (time 1)	Yes		Yes		Yes	
Sibling 2 (time 2)	Yes		Yes		Yes	
Stayers	Yes		Yes		No	
Movers	Yes		No		Yes	
Adjusted for:						
Exposure year	Yes		Yes		Yes	
Maternal variables	Yes		Yes		Yes	
Tract variables	Yes		Yes		Yes	
Maternal fixed effects:	Yes		Yes		Yes	

Abbreviations: CI, confidence interval; Coef., coefficient; NH, non-Hispanic.

Figure 3.1. Forest plot summarizing results of linear regression models by race/ethnicity.



Abbreviations: G, gram; NH, non-Hispanic.

CHAPTER 4

Green selection: Pre-move characteristics, changes in socioeconomic position, and green mobility

Since the early 2000s, accumulating public health research has focused on the benefits of residential greenspace. Hartig et al. (2014), for instance, note in their review of the literature that a Web of Science (previously Web of Knowledge) search using only the terms 'greenspace and health' returns 2 hits for 1990–1999, 34 for 2000–2009, and 45 for 2010–2013. In the years following this influential review (since cited 1,747 times), the same search returns 406 publications.

Multiple reviews on this rapidly growing area of research summarize evidence supporting the salutary effects of greenspace (e.g., Bowler et al., 2010; Frumkin et al., 2017; Hartig et al., 2014; James et al., 2015; Lee & Maheswaran, 2011; Markevych et al., 2017, and others). Greenspace shows protective associations with a range of physical and mental health outcomes, including general health (Dadvand et al., 2016; Sugiyama et al., 2008), mortality (Mitchell & Popham, 2008; Villeneuve et al., 2012), anxiety and depression (de Vries et al., 2013; Fan, Das, & Chen, 2011; Nutsford, Pearson, & Kingham, 2013; Triguero-Mas et al., 2015), birth outcomes (Laurent et al., 2013; 2019; Agay-Shay et al., 2019), and obesity (Ellaway et al., 2005; Gailey et al., 2021; Klompmaker et al., 2018; Pereira et al., 2013; Toftager et al., 2011).

Social and Health Selection

Despite its rising prominence in the literature, a key and often overlooked concern when examining 'neighborhood effects' – or relations between residential environments (including greenspace) and health – involves confounding by a common cause (Glass & Bilal, 2016; Oakes, 2004; Oakes & Rossi, 2003). Unmeasured individual characteristics may precede both residential selection and health outcomes, and correlate with both, thereby biasing neighborhood/health associations. In other words, individuals are not randomly distributed across space. Instead, persons 'select' into neighborhoods (Oakes, 2004).

The two largest sets of potential confounders that may precede both moves to greener neighborhoods and health outcomes involve health and social selection. Healthier individuals, or those of higher socioeconomic position (SEP), may select into (i.e., move to) neighborhoods with more greenspace. For example, more physically active individuals may seek out neighborhoods with greater park access because they provide a venue for outdoor physical activity (Hogendorf et al., 2019). Conversely, preexisting morbidities or limited economic resources may constrain residential mobility (Arcaya et al., 2012; James et al., 2015b) and confine less healthy and lower SEP individuals to more affordable but less green neighborhoods. Thus, selection based on social and health factors represents a key threat to validity in research on the potential benefits of greenspace (Oakes, 2004).

Differences by Race/Ethnicity

If one assumes non-random selection into residential greenspaces, it remains unclear which sociodemographic characteristics predict such moves. For instance, racial/ethnic groups may have different preferences for, or barriers to, living near greenspaces. In studies examining antecedents of park use, for example, racial/ethnic minorities report visiting parks less frequently than do white adults (Floyd et al., 2008; Payne et al., 2002; Tierney et al., 2001). For Black communities in particular, parks and other greenspaces offer limited socio-culturally relevant activities and may provide an unwanted setting for racial abuse and discrimination (Bryne & Wolch, 2009).

Additionally, structural factors in the housing market may inhibit residential selection among racial-ethnic minority families. Systematic racial discrimination, including redlining by mortgage lenders and 'racial steering' by real estate agents, may overshadow individual selection (Squires & Kubrin, 2006). These systematic factors may constrain residential selection among racial/ethnic minorities such that, even with a desire to live in neighborhoods with more greenspace, individual social mobility may not readily translate to such moves.

Current Study & Hypotheses

Residential selection may bias studies of neighborhoods and health (James et al., 2015b). Few studies assess the role of health and social selection on the natural environment. I contribute to this literature by exploring baseline characteristics and changes in SEP that precede 'green mobility,' or moves to neighborhoods with greater greenspace, in a sample of residentially mobile mothers in California. Given that racial/ethnic minorities may have different preferences for, or barriers to, living near greenspace, I also examine whether social and health selection differs for non-Hispanic (NH) white and NH Black mothers. I examine two types of residential greenspace — neighborhood greenness and park access — given that both measures enjoy popular use in the literature on greenspace and health.

I hypothesize that, over time, healthier and higher SEP mothers will move to neighborhoods with greater greenness and park access. In addition, I predict that socioeconomic attainment, as measured by changes in education, will facilitate green mobility in that increases in education will vary with increases in residential greenspace. Since NH Black mothers may have constrained residential options and/or less desire to live near greenspaces, I expect to observe stronger patterns of selection among NH white relative to NH Black mothers. This stronger patterning would manifest as stronger associations (i.e., further from null) between pre-move social and health factors and socioeconomic attainment with subsequent residential greenspace.

Methods

Variables and Data

I retrieved data on live births in California from the California Birth Cohort Files (BCF) for years 2005 to 2015 from the California Department of Public Health (CDPH). I describe the BCF in detail in previous chapters. In 2007, California adopted the 2003 (revised) US Standard Certificate of Birth, which instituted collection of mother's prepregnancy height and weight data (from which I calculated body mass index [BMI], described below) and information on the receipt of Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) benefits. Given that BMI and WIC status represent key health and socioeconomic variables that may play a role in residential selection, I restricted the analysis to live births from January 2007 to December 2015 (n=4,668,445).

Sibling Linkage Strategy & Geocoding

The sibling linkage process, described in detail in Chapter 2, yielded 797,936 sibling pairs, or mothers with at least two live births between 2007 and 2015. I geocoded residential addresses available in sibling-linked birth records using ArcGIS software version 10.4 (Redlands, California). I located point coordinates of addresses using a 2013 street directory and assigned a corresponding census tract (a proxy for neighborhoods) in which these coordinates fell based on 2010 US Census geography.

I excluded mothers if one or both residential addresses in the sibling-linked birth records failed to reach a minimum location match score of 80 percent or with unknown, missing, or non-California census tracts. I further restricted the sample to mothers living in urban California census tracts (6,540 out of 8,057 census tracts) at the time of both births as the neighborhood variables used in this study were validated only for urban areas (n=624,222 mothers / sibling pairs).

Given the focus of this chapter on characteristics associated with residential selection, I restricted the analytic sample to mothers who moved between births. I defined a mother as a 'mover' if her provided residential addresses (located in urban census tracts) differed across birth records. These selection criteria diverge slightly from previous chapters (in which the sample of 'movers' included only mothers who moved to a 'new' census tract). Here, I define the geographic resolution of the park access variable at a buffer of 1 mile surrounding the home. By contrast, the neighborhood greenness variable, used in this and previous chapters, is defined at the census tract level (see details in 'Residential Greenspace Measures,' below) and thus cannot detect within-tract changes. The resulting analytic sample included 288,333 movers, or mothers who moved between consecutive live singleton births in California from 2007 to 2015.

Variables

Sociodemographic Factors

The California BCF for years 2007 to 2015 includes information on demographic and socioeconomic characteristics of the mother. CDPH collects data on maternal race and ethnicity, which I used to classify into the following categories, consistent with the literature: NH white, NH Black, Hispanic, Asian, and other (including unknown and not stated). The BCF also provides data on maternal age (categorized as <20, 20-24, 25-29, 30-34, 35-39, and 40 years or older) and previous live births (i.e., parity, categorized as nulliparous [0 previous live births], primiparous [1 previous live birth], and multiparous [2 or more previous live births]). Demographic characteristics, including race/ethnicity, life stage, and parity, may affect the likelihood of residential mobility, preferences and/or barriers to living near greenspace, and health risks including maternal obesity and low birthweight.

I approximate maternal SEP using several variables, including WIC receipt (yes/no). WIC refers to a federally funded program that provides supplemental nutritious foods and nutrition education to low-income pregnant women and new mothers. The US government provides grants to states to administer WIC. Each state uses a 'means test' of income to determine eligibility. For example, a single parent with one newborn qualifies for WIC in 2021 in California if their annual income is less than $23,606 (US Census, 2021). Given that WIC eligibility depends on demonstration of income below a certain threshold, WIC receipt serves as a useful proxy for low SEP. The BCF also records mother's highest educational attainment (categorized as 8th grade or less, 9th through 12 grade but no diploma, high school graduate or GED, some college credit but no degree, Associate degree, Bachelor's degree, Master's degree, and Doctorate or Professional Degree), and insurance provider (public, private, or self-pay/other) at the time of birth. As discussed in the Introduction, the selective movement of higher SEP mothers (i.e., those not receiving WIC, with higher educational attainment, and private health insurance) into neighborhoods with greater greenspace serves as a key threat to validity in studies of residential greenspace and health.

Health Factors

Body Mass Index. I calculated prepregnancy BMI as weight (kilograms) divided by height (meters) squared for mothers with non-missing, plausible weight (60 lb. — 350 lb.) and height (4'5" — 6'5"). I coded BMI as missing for mothers with height and/or weight data outside of the plausible range (n=23,483 at first birth/sibling 1).

Height and weight data recorded in the birth certificate derive from medical records (preferred) or self-report (in the absence of other sources). Vital records data, such as those contained in the BCF, generally show a high degree of agreement with data collected through medical examination in the National Health and Nutrition Examination Survey (NHANES) (Branum et al., 2014; Ogden et al., 2015). The mean and distributional characteristics of prepregnancy BMI among the study sample also appear similar to a broader set of women of reproductive age (i.e., 18-40), regardless of pregnancy status, in the California Health Interview Survey (CHIS).

Consistent with recent work on health selection (James et al., 2015), I used quartiles of maternal prepregnancy BMI for primary analyses (25th percentile: 21.1, 50th percentile: 23.8, 75th

percentile: 27.8). I also applied standard weight status categories based on CDC guidelines (see details in 'Analysis') for use in sensitivity tests.

Birthweight. The US Standard Certificate of Birth (unrevised and revised) records birthweight in grams (g) at the time of birth. Whereas over 99% of live birth records include stated birthweight, beginning in 1995 not-stated birthweight is imputed from the previous record (i.e., nearest date of birth) with the same period of gestation, race, sex, and plurality. This addition reduces the percentage of not-stated responses for birthweight on average (i.e., across years and states) from 0.11% to 0.01% among live births (CDC, 2003). For this study, I included imputed birthweight but excluded birthweight inconsistent with gestational age (i.e., birthweight implausibly low or high) based on criteria described by Alexander et al. (1996) (n=9,921 at first birth/sibling 1).

As with maternal BMI, I used quartiles of birthweight (g) for primary analyses (25^{th} percentile: 3,005, 50^{th} percentile: 3,312, 75^{th} percentile: 3,620), and WHO standard birthweight categories in sensitivity tests (see details in 'Analysis').

Residential Greenspace Measures

I created two GIS-based measures of residential greenspace. As a point of clarification, throughout this chapter I refer collectively to neighborhood greenness and park access as 'residential greenspace' measures. When referring specifically to one measure, I use the terms below.

Neighborhood Greenness. I retrieved data on neighborhood greenness from the NOAA Climate Data Record (CDR) Normalized Difference Vegetation Index (NDVI) remote sensing product. This process, described in Chapter 2 (p. 30), resulted in one mean NDVI measure per census tract-year. Figures 2.1 and 2.2. provided in Chapter 2 show the distribution of census tract-level NDVI in California over the study period.

Park Access. I obtained GIS-based data on parks from the Environmental Systems Research Institute (ESRI) (Boessen & Hipp, 2018). This dataset [available for download at https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/USA_Parks/FeatureServer/0] includes parks in the United States at the national, state, county, regional, and local levels (see Figure 4.1). ESRI originally collected park data as part of their 2010 StreetMap Data project but provide updates periodically. At the time of my tests, the last update occurred on October 21, 2020.

I defined park access by enumerating national, state, county, regional, and/or local parks of any size within 1 mile of a mother's home. Using ArcGIS, I created a 1-mile buffer around each mother's residential address to determine the total number of parks that fell within the catchment area. I included parks if the centroid was located inside of the buffer (Kaczynski et al., 2014).

Change Scores. I created continuous change scores for both residential greenspace measures. I calculated change scores as post-move residential greenspace (at time 2/second birth) minus pre-move residential greenspace (at time 1/first birth). Positive values represent increases in residential greenspace for both measures.

Analytic Approach

To assess whether pre-move maternal characteristics and changes in SEP predict subsequent residential environments, I conducted linear regressions and specified changes in residential greenspace measures — neighborhood greenness and park access — as dependent variables in separate models (Arcaya et al., 2014; James et al., 2015b). All analyses adjusted for pre-move residential greenspace measures to control for baseline neighborhood factors that may influence residential selection and drive change scores (James et al., 2015b).

I first examined relations between pre-move maternal sociodemographic characteristics and changes in neighborhood greenness and, separately, park access. Sociodemographic characteristics used as independent variables in both models included maternal race/ethnicity, age, parity, WIC receipt, insurance provider, and education level at the time of first birth.

Next, I estimated changes in neighborhood greenness and park access as a function of pre-move health characteristics of the mother and her first birth. Maternal health variables available in the California BCF include prepregnancy height and weight, which I used to calculate BMI. In addition, I examined birthweight — an aspect of infant health — given that (1) birthweight may capture unmeasured (but correlated) aspects of the mother's health that precede downward 'health selection' (i.e., moves to a less green neighborhood), and (2) adverse birth outcomes including lower birthweight may induce additional financial demands that strain families' resources and constrain residential selection. Consistent with James et al. (2015b), I specified quartiles of pre-move health factors (maternal BMI and birthweight) as the key independent variables in separate models predicting change in neighborhood greenness and park access, controlling for pre-move demographic characteristics including maternal age and parity.

Additionally, I assessed whether changes in educational attainment (a proxy for individual social mobility) correspond with changes in neighborhood greenness and park access. I used a 4-level categorical measure of change in education as the key independent variable, where '0' represents no change, and '1,' '2,' and '3' represent increases of 1, 2, and 3 or more levels of educational attainment, respectively, from first to second birth. For example, I coded a change in education level from some college credit (but no degree) to an Associate degree as '1,' to a Bachelor's degree as '2,' and to a Master's, Doctorate, or Professional degree as '3.' Models estimated changes in neighborhood greenness and park access as a function of change in education, controlling for pre-move maternal age and parity.

Lastly, to examine heterogeneity in factors predicting green mobility (i.e., moves to neighborhoods with greater greenspace), I repeated analyses but assessed interactions of maternal race/ethnicity with pre-move health factors and change in education. I further explored any observed interactions by stratifying analyses by maternal race/ethnicity (NH white vs. NH Black). For ease of interpretation, all interaction and stratified models specified continuous measures of health factors and change in education.

Sensitivity Analyses

I also conducted sensitivity tests to assess the robustness of results on pre-move health factors and changes in residential greenspace outcomes to standard health measure cutpoints. I repeated pre-move health factor/greenspace analyses but used, as the key independent variables, categories of BMI based on CDC definitions of normal weight (BMI < 25), overweight (25 ≤ BMI < 30), and obese (BMI ≥ 30); and birthweight based on WHO definitions of very low birthweight (VLBW; <1,500 grams), low birthweight (LBW; <2,500 grams), and normal birthweight (≥2,500 grams).

Results

The analytic sample includes 288,333 mothers who moved to and from urban California census tracts between births delivered from 2007 to 2015. Mothers in this sample represent a broad socioeconomic spectrum and a racially and ethnically diverse population. Table 4.1 shows demographic and socioeconomic characteristics of mothers before and after moving (i.e., at the time of first and second birth). Half of mothers in the analytic sample identified as Hispanic (50.8%) and approximately three quarters were nulliparous (72.5%) and under 30 years of age (74.1%) at the time of first birth. The proportion of mothers with higher SEP increased slightly from pre- to post-move, as indicated by a higher percentage of mothers with at least an Associate degree or higher (31.5%), private health insurance coverage (44.7%), and not enrolled in WIC (44.0%) after moving, relative to before moving (29.3%, 43.9%, and 43.5%, respectively).

Figures 4.2 and 4.3 show the distribution of pre- and post-move neighborhood greenness (in quartiles) and park access (in categories ranging from 0 to 5 or more parks within 1 mile), respectively, overall and among NH white and NH Black mothers. Figure 4.1 indicates that, from pre- to post-move, mothers on average experienced very small increases in neighborhood greenness. For example, across all race/ethnicities, 23.8% of mothers lived in neighborhoods in the highest quartile (Q) of greenness (Q4) after moving, relative to 22.8% before moving. Figure 4.2 also displays large differences in the distribution of neighborhood greenness by race/ethnicity. For example, at both time points, over 36% of NH Black mothers lived in neighborhoods in the lowest quartile of greenness (Q1), compared to less than 18% of NH white mothers.

In contrast to neighborhood greenness, park access appears relatively stable over time and does not differ substantially by race/ethnicity (Figure 4.3). Across both time points and race/ethnicities, more mothers lived within 1 mile of 5 or more parks than any other (lesser) category of park access. This result suggests higher average exposure to parks than neighborhood greenness among mothers in the analytic sample. In addition, unlike neighborhood greenness (see Figure 4.2), Figure 4.3 indicates that a higher proportion of NH Black mothers (61.8%) lived within a mile of 3 or more parks (upper half of the distribution) than NH white mothers (59.5%) after moving.

Pre-Move Sociodemographic & Health Factors

As shown in Table 4.2, the demographic and socioeconomic characteristics of mothers associated with changes in neighborhood greenness and park access differ, although the magnitude of point estimates remains small across outcomes. Results indicate that NH Black and Hispanic (vs.

NH white) race/ethnicity, public (vs. private) health insurance coverage, WIC receipt, older age, and lower parity vary with *decreases* in neighborhood greenness. By contrast, NH Black race/ethnicity, low educational attainment (less than a high school diploma vs. high school diploma), public health insurance coverage, older age, and lower parity vary with *increases* in park access. For example, NH Black race/ethnicity corresponds with a 0.017 decrease (95% confidence interval [CI]: -0.019, -0.015) in neighborhood greenness but a 0.269 increase (95% CI: 0.228, 0.309) in park access.

Table 4.3 presents results of four separate models examining relations between quartiles of pre-move health factors (maternal BMI, birthweight) and changes in residential greenspace (neighborhood greenness, park access). Results indicate that lower quartiles of pre-move BMI and higher quartiles of birthweight in a mother's first birth correspond with increases in neighborhood greenness, consistent with the literature on health selection. Lower quartiles of pre-move BMI also vary with increases in park access. Sensitivity checks using standard cutpoints for health measures generally agree with the original analyses using quartiles of pre-move health factors (Table 4.8).

Change in Education

Table 4.4 shows null relations between changes in education and neighborhood greenness. However, results indicate that a 1-level increase in education varies with a slight increase in park access (coef. = 0.045, CI: 0.010, 0.077). The sign and direction of coefficients support a relation between greater changes in education and park access, but results cannot reject the null.

Differences by Race/Ethnicity

Models including multiplicative interaction terms for pre-move health factors and race/ethnicity show no statistically detectable relations with residential greenspace outcomes (Table 4.6). Results presented in Table 4.5 indicate a positive interaction between change in education and

NH white (vs. NH Black) race/ethnicity and change in park access (coef. = 0.143, CI: 0.071, 0.215). Stratified analyses (Table 4.7) find that increases in education vary with increases in park access for NH white, but not NH Black, mothers (coef. = 0.075, CI: 0.023, 0.126).

Discussion

A large and growing body of literature examines relations between residential greenspace and health (Hartig et al., 2014). Few observational studies, however, assess whether and to what extent baseline individual characteristics predict moves to subsequent residential environments, particularly the availability of greenspace. The selective movement of higher SEP and healthier populations into greener neighborhoods serves as a key threat to validity in studies assessing health benefits conferred by greenspace. I contribute to this literature by investigating pre-move sociodemographic and health factors associated with post-move greenspace in a highly mobile population of over 280,000 mothers in California.

Social and Health Selection

Findings indicate that the maternal characteristics which predict 'green mobility,' or moves to residential areas with greater greenspace, differ according to type of greenspace. Results suggest that NH white race/ethnicity, higher SEP (as approximated by non-WIC status and private health insurance), and younger age at baseline predict *increases* in neighborhood greenness but *decreases* in park access. Further work may uncover why these patterns of selection diverge. For instance, it remains possible that more parks concentrate in higher-density but lower-income urban areas in which NH Black and low-SEP residents disproportionately live. Research that addresses this question, for example, by restricting analysis to parks of a certain size or quality, can advance understanding of the types of green environments that different populations migrate to over time.

In addition, consistent with previous work on 'health selection' (Arcaya et al., 2014; James et al., 2015b), I find that lower BMI and higher weight births before moving correspond with increases in neighborhood greenness and, for pre-move BMI (but not birthweight) park access. These results suggest that past findings on neighborhood greenspace and health, including reduced risks of maternal obesity and low birthweight, may reflect social selection. Based on my results, individuals with better health (e.g., lower BMI, higher birthweight) at baseline may choose to live in neighborhoods with greater greenspace. Contrary to my hypothesis, however, residential selection based on pre-move BMI and birthweight does not appear to differ by race/ethnicity.

The observed relations between pre-move maternal characteristics and post-move residential greenspace support the non-random sorting of mothers into neighborhoods based on sociodemographic and health factors (Oakes, 2004). In general, however, effect sizes across greenspace outcomes remain small, suggesting that bias induced by selection on social and health factors — at least, those available in the birth files — appears relatively limited. Future work that investigates baseline characteristics, including health behaviors (e.g., physical activity) that may predict neighborhood choice, can help illuminate other forces of selection that bias observational studies of neighborhood greenspace effects.

Racial/Ethnic Differences

Individual preferences and structural constraints related to living near greenspace may also drive differential residential selection. For example, prior work suggests that NH Black adults use parks less frequently than do NH whites, possibly owing to limited culturally relevant activities and social exclusion or experiences of perceived discrimination and racial abuse therein (Floyd et al., 2008; Payne et al., 2002; Tierney et al., 2001). Parks, in some cases, may even function as 'social holes' that disrupt social connection or attract crime (Boessen & Hipp, 2018; Hipp et al., 2014). By contrast, NH whites show a strong preference for, and attraction to, wildland and 'naturalistic' green spaces and parks as they provide opportunities for social gatherings and psychological restoration (Bryne, 2012). Accordingly, socioeconomic attainment (insofar as it increases neighborhood options) may differentially predict moves to residential areas with more greenspace according to race/ethnicity.

Examination of associations between changes in education and residential greenspace, and differences among NH white and NH Black mothers, supports this hypothesis. Results in the full sample indicate a weak relation between increases in education and park access. However, interaction and stratified models show that educational attainment corresponds with moves to residential areas with greater park access for NH white, but not NH Black, mothers. This finding suggests that NH white mothers may place relatively higher value on park access, such that socioeconomic attainment facilitates this form of green mobility.

An alternative explanation is that NH white and NH Black mothers may similarly desire to live near greenspaces. However, structural constraints related to residential segregation, which serves to distribute resources unevenly between neighborhoods, may act as a barrier to green mobility in non-white populations. The unequal spatial distribution of greenspace along racial lines is well-documented (in recent years, by Grove et al., 2018; Kronenberg et al., 2020; Liu et al., 2021). NH white and Black residents, moreover, may have different neighborhood 'blind spots' (Krysan & Bader, 2009) such that Black families are more familiar with predominantly Black neighborhoods that lack greenspace, whereas whites are more familiar with majority-white neighborhoods that offer greater access to greenspace. This socially constructed gap, which coincides with structural differences in available neighborhood resources (like greenspace), may partially explain results showing that upwardly mobile white, but not Black, mothers move to neighborhoods with greater park access (Grove et al., 2017).

Limitations and Strengths

A principal limitation of this study includes that it lacks information on relevant area-level contextual factors. For example, an extension of this work could involve assessing the extent to which residential stratification modifies relations of pre-move maternal characteristics and changes in SEP with post-move residential greenspace. I would expect, based on prior research on structurally constrained individual selection, that greater area-level racial segregation weakens residential self-selection into neighborhoods with greater greenspace, particularly among NH Black mothers.

Previous chapters describe the methodological strengths of the matched sibling study design (e.g., its ability to limit confounding due to unmeasured maternal factors) as well as its weaknesses (e.g., limits to external validity). In addition, compared to previous research on residential selection, my study leverages a relatively large analytic sample. In their rigorous work on health selection following Hurricane Katrina, for example, Arcaya, Subramanian, Rhodes, and Waters (2014) involved a sample of 569 survivors. Another study on the topic of residential selection examined 14,159 movers in the Nurses' Health Study (James et al., 2015b). In comparison to these important works, my study of residential selection includes 20 to 500 times more participants, increasing statistical power and permitting detection of heterogeneous patterns of selection in the study population.

Conclusion

Results of this study suggest that sociodemographic and health factors, as well as changes in SEP, may precede selection into neighborhood greenspace among residentially mobile mothers in California. NH white race/ethnicity, higher SEP, and younger age at baseline predict moves to neighborhoods with greater greenness but less park access. Results also provide some evidence of health selection, whereby healthier mothers move to neighborhoods with greater greenspace over time, but associations appear relatively small.

Individual socioeconomic attainment, moreover, may enable green mobility among NH white but not NH Black mothers. Further research on individual preferences and structural factors that motivate or constrain such moves may explain differential residential selection by race/ethnicity. Additionally, it remains unclear whether, or which, life course events predict moves to neighborhoods with more greenspace among NH Black mothers. Taken together, findings underscore the complexity of greenspace/health relations and the importance of research that seeks to understand residential selection in different populations.

Tables & Figures

Table 4.1. Pre-move and post-move maternal sociodemographic characteristics, mothers who moved in California, 2007-2015.

	Pre-move		Post-move	
Characteristic	n	%	n	%
Race/ethnicity				
NH white	72,584	25.17	72,865	25.27
NH Black	22,409	7.77	22,163	7.69
Asian	40,450	14.03	40,372	14.00
Hispanic	146,516	50.81	146,450	50.79
Other, unknown, or not stated	6,374	2.21	6,483	2.25
Education level				
8^{th} grade or less	14,784	5.32	13,814	4.98
9^{th} through 12^{th} grade (no diploma)	53,768	19.35	42,667	15.38
High school graduate or GED	76,143	27.40	75,764	27.31
Some college credit (no degree)	51,680	18.6	57,859	20.86
Associate degree	13,907	5.01	16,411	5.92
Bachelor's degree	43,656	15.71	45,035	16.23
Master's degree	17,532	6.31	19,078	6.88
Doctorate or Professional degree	6,379	2.30	6,783	2.45
Insurance				
Private	126,618	43.91	128,847	44.69
Public	143,830	49.88	142,108	49.29
Self-pay or other	17,885	6.20	17,378	6.03
WIC receipt - yes	160,706	56.54	160,481	55.99
Age at delivery				
<20	46,964	16.29	10,267	3.56
20-24	83,825	29.07	67,161	23.29
25-29	82,742	28.7	82,682	28.68
30-34	57,109	19.81	79,597	27.61
35-39	16,378	5.68	40,650	14.10
≥ 40	1,315	0.46	7,976	2.77
Parity				
1 birth	208,790	72.46	0	0.00
2 births	42,686	14.81	204,933	71.08
3 + births	3,6671	12.73	83,384	28.92

Abbreviations: GED, General Educational Development (test); NH, non-Hispanic; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.

Table 4.2. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks with 1 mile) as a function of pre-move maternal sociodemographic characteristics,[a] mothers who moved in California, 2007-2015.

	Greenness			**Park access**		
Characteristic	Coef.	95% CI		Coef.	95% CI	
Race/ethnicity						
NH white (ref)	--	--	--	--	--	--
NH Black	-0.017	-0.019,	-0.015	0.269	0.228,	0.309
Asian	0.006	0.005,	0.007	0.417	0.386,	0.448
Hispanic	-0.017	-0.018,	-0.016	0.002	-0.025,	0.028
Other, unknown, or not stated	0.001	-0.004,	0.005	0.114	0.002,	0.226
Education level						
8th grade or less	0.011	0.009,	0.013	0.328	0.282,	0.374
9th through 12th grade (no diploma)	0.001	0.000,	0.002	0.096	0.067,	0.126
High school graduate or GED (ref)	--	--	--	--	--	--
Some college credit (no degree)	-0.002	-0.003,	-0.001	-0.025	-0.054,	0.004
Associate degree	0.001	-0.001,	0.003	-0.060	-0.107,	-0.012
Bachelor's degree	0.001	-0.001,	0.002	0.025	-0.012,	0.061
Master's degree	0.005	0.003,	0.007	0.211	0.162,	0.259
Doctorate or Professional degree	0.006	0.003,	0.009	0.079	0.009,	0.150
Insurance						
Private (ref)	--	--	--	--	--	--
Public	-0.005	-0.006,	-0.004	0.057	0.030,	0.084
Self-pay or other	-0.017	-0.019,	-0.016	-0.132	-0.173,	-0.091
WIC receipt - yes	-0.013	-0.014,	-0.011	0.135	0.162,	0.108
Age at delivery						
<20	0.002	0.001,	0.003	-0.033	-0.064,	-0.002
20-24 (ref)	--	--	--	--	--	--
25-29	-0.003	-0.004,	-0.002	0.034	0.008,	0.061
30-34	-0.005	-0.006,	-0.004	0.067	0.035,	0.099
35-39	-0.006	-0.008,	-0.004	0.069	0.022,	0.116
≥ 40	-0.008	-0.014,	-0.002	0.091	-0.052,	0.233
Parity						
1 birth (ref)	--	--	--	--	--	--
2 births	0.009	0.007,	0.010	-0.042	-0.070,	-0.014
3 + births	0.005	0.004,	0.007	-0.098	-0.130,	-0.066

Abbreviations: coef., coefficient; CI, confidence interval; GED, General Educational Development (test); NDVI, Normalized Difference Vegetation Index; NH, non-Hispanic; ref, referent; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children.

[a] Models adjusted for pre-move (left) neighborhood greenness and (right) park access.

Table 4.3. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of pre-move health factors (quartiles),[a] mothers who moved in California, 2007-2015.

Pre-move health factors	**Greenness**			**Park access**		
Maternal BMI	Coef.	95% CI		Coef.	95% CI	
Quartile 1	0.006	0.004,	0.007	0.093	0.065,	0.120
Quartile 2	0.004	0.003,	0.005	0.068	0.041,	0.096
Quartile 3	0.002	0.001,	0.003	0.047	0.020,	0.074
Quartile 4 (ref)	--	--	--	--	--	--
Birthweight	Coef.	95% CI		Coef.	95% CI	
Quartile 1 (ref)	--	--	--	--	--	--
Quartile 2	0.002	0.001,	0.003	-0.0002	-0.027,	0.026
Quartile 3	0.002	0.001,	0.003	-0.025	-0.052,	0.001
Quartile 4	0.004	0.003,	0.005	-0.004	-0.030,	0.023

Abbreviations: coef., coefficient; CI, confidence interval; NDVI, Normalized Difference Vegetation Index; ref, referent.

[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Table 4.4. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of change in education level,[a] mothers who moved in California, 2007-2015.

	Greenness			Park access		
Change in education	Coef.	95% CI		Coef.	95% CI	
No change (ref)	--	--	--	--	--	--
+ 1 level	0.0001	-0.002,	0.001	0.045	0.010,	0.077
+ 2 levels	0.002	-0.0001,	0.004	0.017	-0.047,	0.079
+ 3 or more levels	-0.003	-0.008,	0.003	0.081	-0.056,	0.218

Abbreviations: coef., coefficient; CI, confidence interval; NDVI, Normalized Difference Vegetation Index; ref, referent.
[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Table 4.5. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of the interaction between change in education level and maternal race/ethnicity (NH white vs. NH Black), mothers who moved in California, 2007-2015.

	Greenness		**Park access**	
	Coef.	95% CI	Coef.	95% CI
Change in education	0.001	-0.001, 0.003	-0.039	-0.094, 0.017
NH white (vs. NH Black)	0.004	-0.001, 0.003	-0.251	-0.299, -0.203
Interaction	-0.001	-0.003, 0.002	0.143	0.071, 0.215

Abbreviations: coef., coefficient; CI, confidence interval; NDVI, Normalized Difference Vegetation Index; ref, referent.

[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Table 4.6. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of the interaction between pre-move health factors (continuous) and maternal race/ethnicity (NH white vs. NH Black), mothers who moved in California, 2007-2015.

Pre-move health factors	**Greenness**			**Park access**		
	Coef.	95% CI		Coef.	95% CI	
Maternal BMI	-0.0002	-0.001,	-0.0001	-0.001	-0.005,	0.003
NH white (vs. NH Black)	0.006	-0.001,	0.012	-0.229	-0.375,	-0.082
Interaction	-0.001	-0.003	0.002	-0.002	-0.008,	0.003
Birthweight	0.000	0.000,	0.000	0.000	0.000,	0.000
NH white (vs. NH Black)	-0.006	-0.015,	0.003	-0.003	-0.253,	0.246
Interaction	0.0001	-0.001,	0.002	-0.001	-0.001,	0.001

Abbreviations: coef., coefficient; CI, confidence interval; NDVI, Normalized Difference Vegetation Index; ref, referent.
[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Table 4.7. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of change in education level, by race/ethnicity, mothers who moved in California, 2007-2015.

	Greenness		Park access	
	Coef.	95% CI	Coef.	95% CI
NH white	0.001	-0.002, 0.002	0.075	0.023, 0.126
NH Black	-0.001	-0.003, 0.002	-0.016	-0.085, 0.054

Abbreviations: coef., coefficient; CI, confidence interval; NDVI, Normalized Difference Vegetation Index; NH, non-Hispanic.

[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Table 4.8. Coefficients (coef.) and 95% confidence intervals (CI) predicting change in (left) neighborhood greenness (census tract-level NDVI) and (right) park access (number of parks within 1 mile) as a function of pre-move health factors (categorical cutpoints),[a] mothers who moved in California, 2007-2015.

Pre-move health factors	**Greenness**			**Park access**		
	Coef.	95% CI		Coef.	95% CI	
Maternal BMI						
Healthy (<25)	0.005	0.004,	0.006	0.088	0.061,	0.115
Overweight (25-29.9)	0.002	0.0003,	0.003	0.054	0.023,	0.084
Obese (≥ 30)	--	--	--	--	--	--
Birthweight						
VLBW (<1,500 grams)	--	--	--	--	--	--
LBW (1,500-2,499 grams)	0.002	-0.004,	0.007	0.001	-0.120,	0.122
Healthy (≥ 2,500 grams)	0.002	-0.003,	0.007	-0.037	-0.150,	0.077

Abbreviations: coef., coefficient; CI, confidence interval; LBW, low birthweight; NDVI, Normalized Difference Vegetation Index; ref, referent; VLBW, very low birthweight.

[a] Models adjusted for pre-move age, parity, and (left) neighborhood greenness and (right) park access.

Figure 4.1. National, State, County, Regional, and Local Parks, Southern California (selected area), 2020.

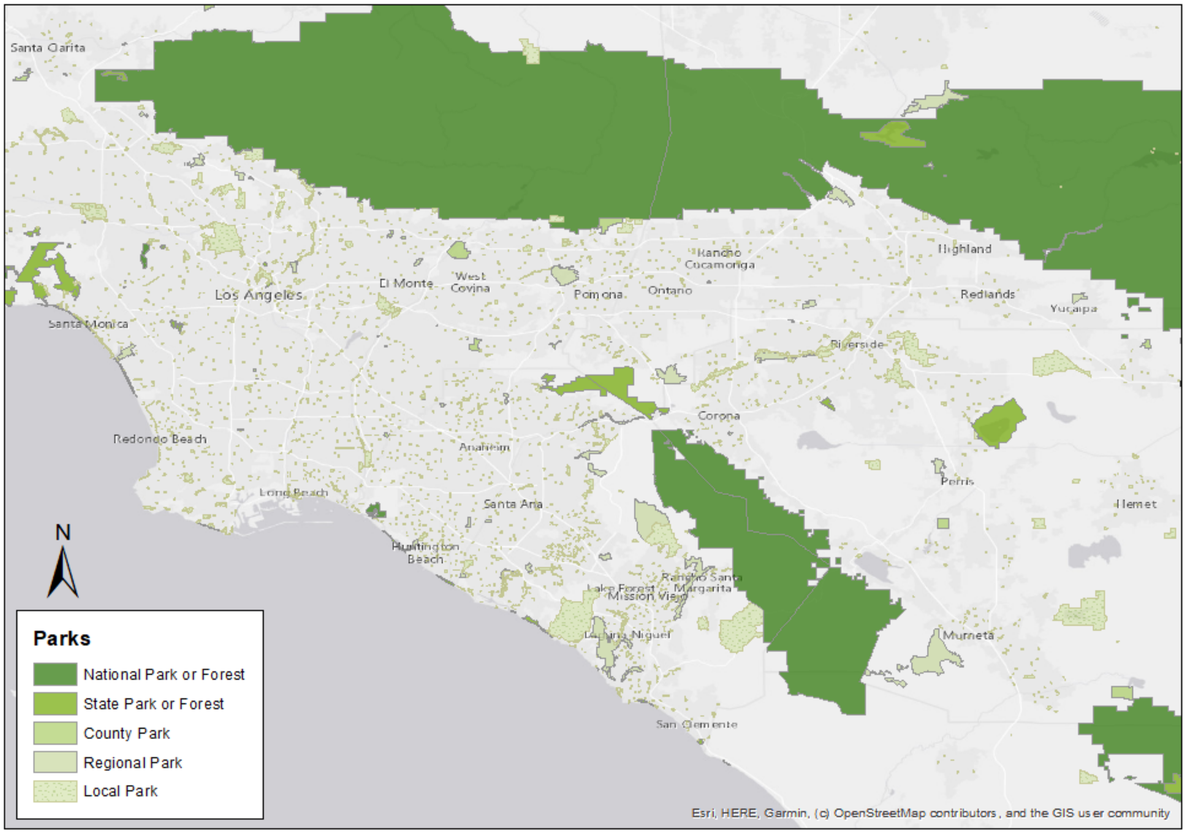


Figure 4.2. Distribution of pre-move and post-move neighborhood greenness (categorized by quartile of tract-level NDVI), mothers who moved in California, 2007-2015.

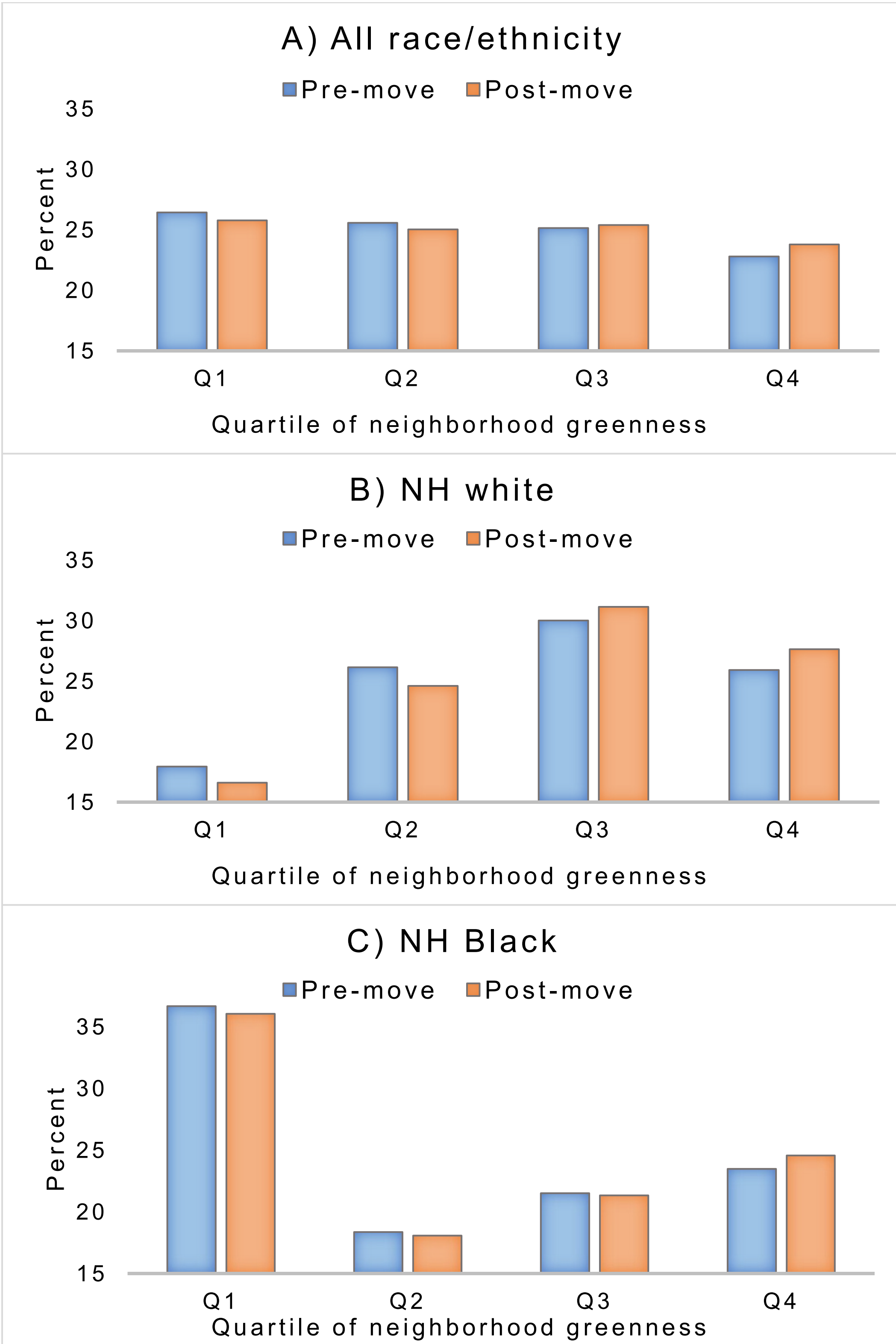
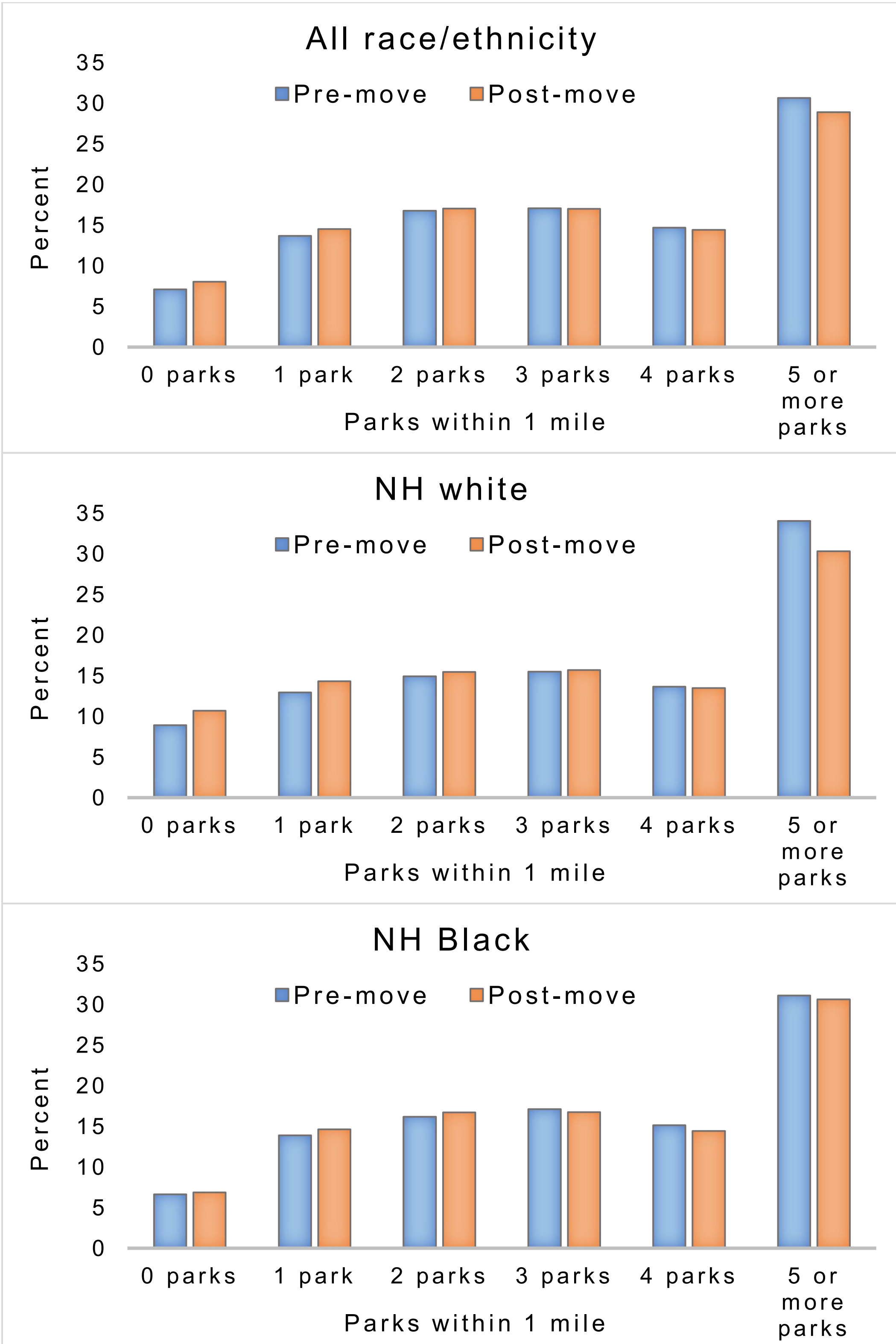


Figure 4.3. Distribution of pre-move and post-move park access (categorized by number of parks within 1 mile), mothers who moved in California, 2007-2015.



CHAPTER 5

Concluding remarks

By 2050, nearly two-thirds of the global population will live in urban areas (UN World Urbanization Prospects, 2018). Rapid urbanization both in and outside of the US has sparked an explosion of research on the importance of conserving and propagating natural environments. A subset of this work focuses on the benefits of nature, or 'greenspace,' for human health. Nearly 500 articles on this topic — published in the last two decades alone — examine and document protective associations between greenspace and societally-relevant health outcomes, including maternal and perinatal health. Very few studies, however, employ methods that can infer causality. In particular, the selective movement of healthier or socioeconomically advantaged populations to residentially greener environments remains an important threat to internal validity of most studies in this area.

Summary of Main Findings

My dissertation advances this literature by (a) leveraging unique, sibling-linked longitudinal data to improve causal inference in relations between greenspace and health, (b) conducting theoretically motivated tests of heterogeneity by individual sociodemographic characteristics, and (c) assessing the extent of bias induced by residential selection: a key, and often overlooked, threat to validity in studies of neighborhood effects.

Following a review of the literature (Chapter 1), Chapter 2 longitudinally examined whether and to what extent 'green mobility,' or moving to a greener neighborhood, reduces the risk of maternal obesity. Results, controlling for baseline obesity status, indicate that upward green mobility varies inversely with obesity risk. Chapter 3 assessed cross-sectional and longitudinal relations between neighborhood greenness and birth outcomes, focusing on mothers who do not move but experience within-neighborhood increases in greenness between births (mimicking an intervention). Results show that non-Hispanic (NH) Black mothers — who, in the US, exhibit the highest risk of adverse birth outcomes — deliver higher weight births following increases in neighborhood greenness. Results in NH white mothers, by contrast, indicate a cross-sectional relation between greenness and birthweight, but no longer reject the null in 'within-mother' analyses that adjust for unmeasured confounders involved in residential selection. Chapter 4 more formally investigated the role of social and health selection in moves to neighborhoods with greater greenness and park access. Results suggest that residential selection into neighborhood greenspace induces minimal bias in the study population but leaves open important questions of how and why NH white and NH Black mothers differ in their mobility patterns.

Taken together, findings from my program of research suggest, consistent with past work, that residential greenspace does confer health benefits, including reduced risks of obesity and adverse birth outcomes. Importantly, benefits — at least in terms of higher birthweight — appear to concentrate in NH Black mothers, who remain more than twice as likely to deliver preterm and small-for-gestational age births. The role of residential greenspace in health appears less certain for NH white mothers, who may move to greener neighborhoods based on factors that also correlate with better health. Selection into and out of residential greenspace, in particular, deserves more attention in the literature. Findings can shed light on whether urban greening and other neighborhood-level interventions that increase greenspace can deliver population health benefits, or rather, should target disparities in health among vulnerable groups (e.g., NH Black mothers).

Future Directions

Whereas my program of research advances the literature by identifying plausibly causal relations between greenspace and perinatal health, the mechanisms underlying these relations remain unclear. Past work suggests that nature may operate through multiple interacting pathways, including stress recovery, encouraging physical activity, fostering social support, and mitigating environmental risks such as air pollution and extreme heat (see Figure 1.1). However, empirical examination of such processes remains scarce. Understanding these diverse multi-level pathways may require novel methodological approaches. Few population-based longitudinal datasets, for instance, include both geographic and individual-level measures. Rather than rely on secondary data sources, researchers who leverage innovative techniques to collect psychological, behavioral, and environmental data may better address questions of *how* greenspace affects health. For example, advances in remote-sensing technologies (e.g., smartphone-based activity tracking) can facilitate improved studies of whether living in greener neighborhoods promotes more active forms of transportation (e.g., walking or cycling to work).

The types of greenspace that affect health-promoting mechanisms and outcomes also warrant further investigation. For instance, evolutionary theories posit that natural settings characterized as 'favorable to pre-modern humans from the standpoint of yielding food and drinking water' elicit more restorative responses than other forms of nature (Ulrich et al., 1984, p. 205). Ulrich advances the hypothesis that savanna-like landscapes, which humans perceive as affording access to sustenance and shelter, evoke rapid affective responses that promote stress recovery. Human-made urban parks and trails, which share few similarities with natural savanna-like settings, may offer limited respite from stressful experiences, but rather may encourage physical activity and reduce obesity risk. By contrast, areas with dense canopies of conifer trees may remove particulate matter and mitigate asthma severity. As these examples demonstrate, understanding how different natural environments affect health can aid interventions targeting different outcomes.

Individual experiences and acculturation may also modify which types of natural environments elicit salutary psychological and behavioral responses. Familiarity, for example, remains among the strongest predictors of preference for environmental features, which may in turn influence whether an individual experiences restoration (or other benefits) in the presence of certain environments (Falk & Balling, 2010). At a population level, variation across individuals of different race, ethnicity, gender, and nationality may also predict different individual-level responses that scale to group-level differences in greenspace/health relations. For instance, NH Black populations report visiting urban parks less frequently than other race/ethnicities, in part owing to structural practices that limit their access, and personal experiences of discrimination within these spaces (Bryne & Wolch, 2009).

Relations between greenspace and health show substantial heterogeneity. Simply put, different types of greenspace may confer different benefits to different populations. To better understand these diverse relations, researchers should move beyond observational methods that have enjoyed widespread use over the past three decades. For example, urban greening projects, which have gained popularity (and funding) in recent years, provide researchers with a setting for quasi-experimental study designs. Combined with novel data collection techniques like smartphone-based apps that capture psychological and behavioral data with geographic and temporal precision, these urban and methodological developments offer a promising new direction for research assessing how, why, and for whom greenspace benefits health. Given that pathways underlying greenspace/health relations appear varied, a social-ecological perspective can help researchers understand how these processes unfold across time and place.

References

Anderson, N. B., & Armstead, C. A. (1995). Toward understanding the association of socioeconomic status and health: A new challenge for the biopsychosocial approach. *Psychosomatic Medicine, 57*(3), 213-225.

Agay-Shay, K., Peled, A., Crespo, A. V., Peretz, C., Amitai, Y., Linn, S., … Nieuwenhuijsen, M. J. (2014). Green spaces and adverse pregnancy outcomes. *Occupational and Environmental Medicine*, *71*(8), 562–569. https://doi.org/10.1136/oemed-2013-101961

Agay-Shay, K., Michael, Y., Basagaña, X., Martínez-Solanas, È., Broday, D., Lensky, I. M., Rudolf, M., Rubin, L., Kent, R., Levy, N., Haklai, Z., & Grotto, I. (2019). Mean and variance of greenness and pregnancy outcomes in Tel Aviv during 2000–14: Longitudinal and cross-sectional approaches. *International Journal of Epidemiology*, *48*(4), 1054–1072. https://doi.org/10.1093/ije/dyy249

Agyemang, C., van Hooijdonk, C., Wendel-Vos, W., Ujcic-Voortman, J. K., Lindeman, E., Stronks, K., & Droomers, M. (2007). Ethnic differences in the effect of environmental stressors on blood pressure and hypertension in the Netherlands. *BMC Public Health*, *7*(1), 118. https://doi.org/10.1186/1471-2458-7-118

Arcaya, M. C., Subramanian, S. V., Rhodes, J. E., & Waters, M. C. (2014). Role of health in predicting moves to poor neighborhoods among Hurricane Katrina survivors. *Proceedings of the National Academy of Sciences*, *111*(46), 16246–16253. https://doi.org/10.1073/pnas.1416950111

Astell-Burt, T., Feng, X., & Kolt, G. S. (2014). Greener neighborhoods, slimmer people? Evidence from 246 920 Australians. *International Journal of Obesity*, *38*(1), 156–159. https://doi.org/10.1038/ijo.2013.64

Austin, M.-P., & Leader, L. (2000). Maternal stress and obstetric and infant outcomes: epidemiological findings and neuroendocrine mechanisms. *The Australian and New Zealand Journal of Obstetrics and Gynaecology*, *40*(3), 331–337. https://doi.org/10.1111/j.1479-828X.2000.tb03344.x

Banay, R. F., Bezold, C. P., James, P., Hart, J. E., & Laden, F. (2017). Residential greenness: Current perspectives on its impact on maternal health and pregnancy outcomes. *International Journal of Women's Health*, *9*, 133–144. https://doi.org/10.2147/IJWH.S125358

Baron, R. M., & Kenny, D. A. (1986). *The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations*. 10.

Behrman, R. E., & Butler, A.S. (2007). *Preterm Birth*. National Academies Press (US). https://doi.org/10.17226/11622

Beijers, R., Buitelaar, J. K., & de Weerth, C. (2014). Mechanisms underlying the effects of prenatal psychosocial stress on child outcomes: beyond the HPA axis. *European Child & Adolescent Psychiatry*, *23*(10), 943–956. https://doi.org/10.1007/s00787-014-0566-3

Bell, J. F., Wilson, J. S., & Liu, G. C. (2008). Neighborhood greenness and 2-Year changes in body mass index of children and youth. *American Journal of Preventive Medicine*, *35*(6), 547–553. https://doi.org/10.1016/j.amepre.2008.07.006

Benmarhnia Tarik, Huang Jonathan, Basu Rupa, Wu Jun, & Bruckner Tim A. (2017). Decomposition Analysis of Black–White Disparities in Birth Outcomes: The Relative Contribution of Air Pollution and Social Factors in California. *Environmental Health Perspectives*, *125*(10), 107003. https://doi.org/10.1289/EHP490

Benton, J. S., Cotterill, S., Anderson, J., Macintyre, V. G., Gittins, M., Dennis, M., Lindley, S. J., & French, D. P. (2021). Impact of a low-cost urban green space intervention on wellbeing behaviours in older adults: A natural experimental study. *Wellbeing, Space and Society*, 100029. https://doi.org/10.1016/j.wss.2021.100029

Berlyne, D. E. (1971). Aesthetics and psychobiology (Vol. 336). New York: Appleton-Century-Crofts.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The Cognitive Benefits of Interacting With Nature. *Psychological Science*, *19*(12), 1207–1212. https://doi.org/10.1111/j.1467-9280.2008.02225.x

Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, *25*(3), 249–259. https://doi.org/10.1016/j.jenvp.2005.07.001

Beydoun, H., & Saftlas, A. F. (2008). Physical and mental health outcomes of prenatal maternal stress in human and animal studies: A review of recent evidence. *Paediatric and Perinatal Epidemiology*, *22*(5), 438–466. https://doi.org/10.1111/j.1365-3016.2008.00951.x

Birth registration handbook. (2016). California Department of Public Health – Vital Records [CDPH – VR]. http://www.avss.ucsb.edu/MANUALS/Handbook.pdf

Boessen, A., & Hipp, J. R. (2018). Parks as crime inhibitors or generators: Examining parks and the role of their nearby context. *Social Science Research*, *76*, 186–201. https://doi.org/10.1016/j.ssresearch.2018.08.008

Bowler, D. E., Buyung-Ali, L. M., Knight, T. M., & Pullin, A. S. (2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health*, *10*(1), 456. https://doi.org/10.1186/1471-2458-10-456

Brack, C. L. (2002). Pollution mitigation and carbon sequestration by an urban forest. *Environmental Pollution*, *116*, S195–S200. https://doi.org/10.1016/S0269-7491(01)00251-2

Branum, A. M., Kirmeyer, S. E., & Gregory, E. C. (2016). Prepregnancy body mass index by maternal characteristics and state: Data from the birth certificate, 2014. *National Vital Statistics Reports: From the Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System*, *65*(6), 1–11.

Browning, M., & Lee, K. (2017). Within what distance does "greenness" best predict physical health? A systematic review of articles with GIS buffer analyses across the lifespan. *International Journal of Environmental Research and Public Health*, *14*(7), 675. https://doi.org/10.3390/ijerph14070675

Bruckner, T. A., Lebreton, É., Perrone, N., Mortensen, L. H., & Blondel, B. (2019). Preterm birth and selection in utero among males following the November 2015 Paris attacks. *International Journal of Epidemiology*, *48*(5), 1614–1622. https://doi.org/10.1093/ije/dyz089

Byrne, J. (2012). When green is White: The cultural politics of race, nature and social exclusion in a Los Angeles urban national park. *Geoforum*, *43*(3), 595–611. https://doi.org/10.1016/j.geoforum.2011.10.002

Byrne, J., & Wolch, J. (2009). Nature, race, and parks: Past research and future directions for geographic research. *Progress in Human Geography*, *33*(6), 743–765. https://doi.org/10.1177/0309132509103156

Casey, J. A., James, P., Rudolph, K. E., Wu, C.-D., & Schwartz, B. S. (2016). Greenness and Birth Outcomes in a Range of Pennsylvania Communities. *International Journal of Environmental Research and Public Health*, *13*(3), 311. https://doi.org/10.3390/ijerph13030311

Centers for Disease Control (CDC). (2003). Birth edit specifications for the 2003 proposed revision of the U.S. Standard Certificate of Birth. http://www.cdc.gov/nchs/data/dvs/birth_edit_specifications.pdf

Cohen, S. (1978). Environmental load and the allocation of attention. Advances in environmental psychology, 1, 1-29.

Cohen, S., Janicki-Deverts, D., & Miller, G. E. (2007). Psychological Stress and Disease. *JAMA*, *298*(14), 1685–1687. https://doi.org/10.1001/jama.298.14.1685

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

Cummins, S., & Fagg, J. (2012). Does greener mean thinner? Associations between neighbourhood greenspace and weight status among adults in England. *International Journal of Obesity*, *36*(8), 1108–1113. https://doi.org/10.1038/ijo.2011.195

Cusack, L., Larkin, A., Carozza, S. E., & Hystad, P. (2017). Associations between multiple green space measures and birth weight across two US cities. *Health & Place*, *47*, 36–43. https://doi.org/10.1016/j.healthplace.2017.07.002

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

Dadvand, P., de Nazelle, A., Figueras, F., Basagaña, X., Su, J., Amoly, E., Jerrett, M., Vrijheid, M., Sunyer, J., & Nieuwenhuijsen, M. J. (2012). Green space, health inequality and pregnancy. *Environment International*, *40*, 110–115. https://doi.org/10.1016/j.envint.2011.07.004

Dadvand, P., Wright, J., Martinez, D., Basagaña, X., McEachan, R. R. C., Cirach, M., Gidlow, C. J., de Hoogh, K., Gražulevičienė, R., & Nieuwenhuijsen, M. J. (2014). Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status. *Environment International*, *71*, 101–108. https://doi.org/10.1016/j.envint.2014.06.010

Davey Smith, G., Blane, D., & Bartley, M. (1994). Explanations for socio-economic differentials in mortality: Evidence from Britain and elsewhere. *European Journal of Public Health*, *4*(2), 131–144. https://doi.org/10.1093/eurpub/4.2.131

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

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

Dimberg, U. (1986). Facial reactions to fear-relevant and fear-irrelevant stimuli. *Biological Psychology*, *23*(2), 153–161. https://doi.org/10.1016/0301-0511(86)90079-7

Dominguez, T. P., Dunkel-Schetter, C., Glynn, L. M., Hobel, C., & Sandman, C. A. (2008). Racial Differences in Birth Outcomes: The Role of General, Pregnancy, and Racism Stress. *Health*

Psychology : Official Journal of the Division of Health Psychology, American Psychological Association, *27*(2), 194–203. https://doi.org/10.1037/0278-6133.27.2.194

Donovan, G. H., Michael, Y. L., Butry, D. T., Sullivan, A. D., & Chase, J. M. (2011). Urban trees and the risk of poor birth outcomes. *Health & Place*, *17*(1), 390–393. https://doi.org/10.1016/j.healthplace.2010.11.004

Dzhambov, A. M., Dimitrova, D. D., & Dimitrakova, E. D. (2014). Association between residential greenness and birth weight: Systematic review and meta-analysis. *Urban Forestry & Urban Greening*, *13*(4), 621–629. https://doi.org/10.1016/j.ufug.2014.09.004

Ebisu, K., Holford, T. R., & Bell, M. L. (2016). Association between greenness, urbanicity, and birth weight. *Science of The Total Environment*, *542*, 750–756. https://doi.org/10.1016/j.scitotenv.2015.10.111

Ellaway, A., Macintyre, S., & Bonnefoy, X. (2005). Graffiti, greenery, and obesity in adults: Secondary analysis of European cross sectional survey. *BMJ*, *331*(7517), 611–612. https://doi.org/10.1136/bmj.38575.664549.F7

Ender, P. (2011). Indirect effects with binary dv and/or mv. UCLA: Academic Technology Services, Statistical Consulting Group. Available at: http://www. ats. ucla. edu/stat/stata/ado/analysis/.[Accessed 20 th Feb 2012].

Falk, J. H., & Balling, J. D. (2010). Evolutionary influence on human landscape preference. *Environment and Behavior*, *42*(4), 479-493.

Fan, Y., Das, K. V., & Chen, Q. (2011). Neighborhood green, social support, physical activity, and stress: Assessing the cumulative impact. *Health & Place*, *17*(6), 1202–1211. https://doi.org/10.1016/j.healthplace.2011.08.008

Fedorcsák, P., Storeng, R., Dale, P. O., Tanbo, T., & Abyholm, T. (2000). Obesity is a risk factor for early pregnancy loss after IVF or ICSI. *Acta Obstetricia Et Gynecologica Scandinavica*, *79*(1), 43–48.

Floyd, M. F., Spengler, J. O., Maddock, J. E., Gobster, P. H., & Suau, L. (2008). Environmental and Social Correlates of Physical Activity in Neighborhood Parks: An Observational Study in Tampa and Chicago. *Leisure Sciences*, *30*(4), 360–375. https://doi.org/10.1080/01490400802165156

Frisell, T., Öberg, S., Kuja-Halkola, R., & Sjölander, A. (2012). Sibling Comparison Designs: Bios From Non-Shored Confounders and Measurement Error. *Epidemiology*, *23*(5), 713–720. JSTOR. https://www.jstor.org/stable/41739651

Frisell, T. (2020). Sibling comparison designs, are they worth the effort? *American Journal of Epidemiology*. https://doi.org/10.1093/aje/kwaa183

Frumkin Howard, Bratman Gregory N., Breslow Sara Jo, Cochran Bobby, Kahn Jr Peter H., Lawler Joshua J., Levin Phillip S., Tandon Pooja S., Varanasi Usha, Wolf Kathleen L., & Wood Spencer A. (2017). Nature contact and human health: A research agenda. *Environmental Health Perspectives*, *125*(7), 075001. https://doi.org/10.1289/EHP1663

Gailey, S., & Bruckner, T. A. (2019). Obesity among black women in food deserts: An "omnibus" test of differential risk. *SSM-Population Health*, 7, 100363. https://doi.org/10.1016/j.ssmph.2019.100363

Gailey, S., McElroy, S., Benmarhnia, T., & Bruckner, T. A. (2021). Green mobility and obesity risk: A longitudinal analysis in California. *Health & Place*, *68*, 102503. https://doi.org/10.1016/j.healthplace.2020.102503

Gee, C.& Payne-Sturges, D. (2004). Environmental Health Disparities: A Framework Integrating Psychosocial and Environmental Concepts. *Environmental Health Perspectives*, *112*(17), 1645–1653. https://doi.org/10.1289/ehp.7074

Gemmill, A., Catalano, R., Casey, J. A., Karasek, D., Alcalá, H. E., Elser, H., & Torres, J. M. (2019). Association of Preterm Births Among US Latina Women With the 2016 Presidential Election. *JAMA Network Open*, *2*(7), e197084. https://doi.org/10.1001/jamanetworkopen.2019.7084

Gidlöf-Gunnarsson, A., & Öhrström, E. (2007). Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. *Landscape and Urban Planning*, *83*(2), 115–126. https://doi.org/10.1016/j.landurbplan.2007.03.003

Giscombé, C. L., & Lobel, M. (2005). Explaining Disproportionately High Rates of Adverse Birth Outcomes Among African Americans: The Impact of Stress, Racism, and Related Factors in Pregnancy. *Psychological Bulletin*, *131*(5), 662–683. https://doi.org/10.1037/0033-2909.131.5.662

Glass, T. A., & Bilal, U. (2016). Are neighborhoods causal? Complications arising from the 'stickiness' of ZNA. *Social Science & Medicine*, *166*, 244–253. https://doi.org/10.1016/j.socscimed.2016.01.001

Goldenberg, R. L., Culhane, J. F., Iams, J. D., & Romero, R. (2008). Epidemiology and causes of preterm birth. *The Lancet*, *371*(9606), 75–84. https://doi.org/10.1016/S0140-6736(08)60074-4

Gould, J. B. (1999). Vital Records for Quality Improvement. *Pediatrics*, *103*(Supplement E1), 278–290.

Gould, K.A., & Lewis, T. L. (2012). The environmental injustice of green gentrification. In: DeSena, J., & Shortell, T. (eds.). *The World in Brooklyn: Gentrification, Immigration, and Ethnic Politics in a Global City*. Lexington Books: Lanham, UK.

Gronlund, C. J., Berrocal, V. J., White-Newsome, J. L., Conlon, K. C., & O'Neill, M. S. (2015). Vulnerability to extreme heat by socio-demographic characteristics and area green space among the elderly in Michigan, 1990–2007. *Environmental Research*, *136*, 449–461. https://doi.org/10.1016/j.envres.2014.08.042

Grove, M., Ogden, L., Pickett, S., Boone, C., Buckley, G., Locke, D. H., Lord, C., & Hall, B. (2018). The Legacy Effect: Understanding How Segregation and Environmental Injustice Unfold over Time in Baltimore. *Annals of the American Association of Geographers*, *108*(2), 524–537. https://doi.org/10.1080/24694452.2017.1365585

Gunatilake, R. P., & Perlow, J. H. (2011). Obesity and pregnancy: Clinical management of the obese gravida. *American Journal of Obstetrics and Gynecology*, *204*(2), 106–119. https://doi.org/10.1016/j.ajog.2010.10.002

Gwynn R C & Thurston G D. (2001). The burden of air pollution: Impacts among racial minorities. *Environmental Health Perspectives*, *109*(suppl 4), 501–506. https://doi.org/10.1289/ehp.01109s4501

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

Hartig, T., & Kahn, P. H. (2016). Living in cities, naturally. *Science*, *352*(6288), 938–940. https://doi.org/10.1126/science.aaf3759

Hartig, T., Mang, M., & Evans, G. W. (1991). Restorative Effects of Natural Environment Experiences. *Environment and Behavior*, *23*(1), 3–26. https://doi.org/10.1177/0013916591231001

Hartig, T., Mitchell, R., de Vries, S., & Frumkin, H. (2014). Nature and Health. *Annual Review of Public Health*, *35*(1), 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443

Hedegaard, M., Henriksen, T. B., Sabroe, S., & Secher, N. J. (1993). Psychological distress in pregnancy and preterm delivery. *BMJ*, *307*(6898), 234–239. https://doi.org/10.1136/bmj.307.6898.234

Hipp, J. R., Corcoran, J., Wickes, R., & Li, T. (2014). Examining the Social Porosity of Environmental Features on Neighborhood Sociability and Attachment. *PLOS ONE*, *9*(1), e84544. https://doi.org/10.1371/journal.pone.0084544

Hobel, C. J., Goldstein, A. M. Y., & Barrett, E. S. (2008). Psychosocial stress and pregnancy outcome. *Clinical Obstetrics and Gynecology, 51*(2), 333-348.

Hogendorf, M., Oude Groeniger, J., Noordzij, J. M., Beenackers, M. A., & van Lenthe, F. J. (2019). Longitudinal effects of urban green space on walking and cycling: A fixed effects analysis. *Health & Place*, 102264. https://doi.org/10.1016/j.healthplace.2019.102264

Holmes, M. E., Ekkekakis, P., & Eisenmann, J. C. (2010). The physical activity, stress and metabolic syndrome triangle: A guide to unfamiliar territory for the obesity researcher. *Obesity Reviews*, *11*(7), 492–507. https://doi.org/10.1111/j.1467-789X.2009.00680.x

Holt-Lunstad, J., Smith, T. B., & Layton, J. B. (2010). Social Relationships and Mortality Risk: A Meta-analytic Review. *PLOS Medicine*, *7*(7), e1000316. https://doi.org/10.1371/journal.pmed.1000316

Hutcheon, J. A., & Harper, S. (2019). Invited commentary: Promise and pitfalls of the sibling comparison design in studies of optimal birth spacing. *American Journal of Epidemiology*, *188*(1), 17–21. https://doi.org/10.1093/aje/kwy195

Hystad, P., Davies, H. W., Frank, L., Van Loon, J., Gehring, U., Tamburic, L., & Brauer, M. (2014). Residential greenness and birth outcomes: Evaluating the influence of spatially correlated built-environment factors. *Environmental Health Perspectives*, *122*(10), 1095–1102. https://doi.org/10.1289/ehp.1308049

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

James, P., Hart, J. E., Arcaya, M. C., Feskanich, D., Laden, F., & Subramanian, S. V. (2015b). Neighborhood Self-Selection: The Role of Pre-Move Health Factors on the Built and Socioeconomic Environment. *International Journal of Environmental Research and Public Health*, *12*(10), 12489–12504. https://doi.org/10.3390/ijerph121012489

James, W. (1892). *Textbook of Psychology*. Macmillan.

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

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

Kaplan, R. (2001). The Nature of the View from Home: Psychological Benefits. *Environment and Behavior*, *33*(4), 507–542. https://doi.org/10.1177/00139160121973115

Kaplan, R., & Kaplan, S. (1989). *The Experience of Nature: A Psychological Perspective*. CUP Archive.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2

King, K. E., Morenoff, J. D., & House, J. S. (2011). Neighborhood context and social disparities in cumulative biological risk factors. *Psychosomatic Medicine*, *73*(7), 572–579. https://doi.org/10.1097/PSY.0b013e318227b062

Klompmaker, J. O., Hoek, G., Bloemsma, L. D., Gehring, U., Strak, M., Wijga, A. H., van den Brink, C., Brunekreef, B., Lebret, E., & Janssen, N. A. H. (2018). Green space definition affects associations of green space with overweight and physical activity. *Environmental Research*, *160*, 531–540. https://doi.org/10.1016/j.envres.2017.10.027

Kondo, M. C., Jacoby, S. F., & South, E. C. (2018). Does spending time outdoors reduce stress? A review of real-time stress response to outdoor environments. *Health & Place*, *51*, 136–150. https://doi.org/10.1016/j.healthplace.2018.03.001

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

Krueger, P. M., Coleman-Minahan, K., & Rooks, R. N. (2014). Race/ethnicity, nativity and trends in BMI among U.S. adults. *Obesity*, *22*(7), 1739–1746. https://doi.org/10.1002/oby.20744

Krysan, M., & Bader, M. D. M. (2009). Racial Blind Spots: Black-White-Latino Differences in Community Knowledge. *Social Problems*, *56*(4), 677–701. https://doi.org/10.1525/sp.2009.56.4.677

Kuo, F. E. (2001). Coping with Poverty: Impacts of Environment and Attention in the Inner City. *Environment and Behavior*, *33*(1), 5–34. https://doi.org/10.1177/00139160121972846

Kuo, F. E., & Taylor, A. (2004). A Potential Natural Treatment for Attention-Deficit/Hyperactivity Disorder: Evidence From a National Study. *American Journal of Public Health*, *94*(9), 1580–1586. https://doi.org/10.2105/AJPH.94.9.1580

Lachowycz, K., & Jones, A. P. (2011). Greenspace and obesity: A systematic review of the evidence. *Obesity Reviews*, *12*(5), e183–e189. https://doi.org/10.1111/j.1467-789X.2010.00827.x

Lake, A., & Townshend, T. (2006). Obesogenic environments: Exploring the built and food environments. *Journal of the Royal Society for the Promotion of Health*, *126*(6), 262–267. https://doi.org/10.1177/1466424006070487

Lashen, H., Fear, K., & Sturdee, D. W. (2004). Obesity is associated with increased risk of first trimester and recurrent miscarriage: Matched case–control study. *Human Reproduction*, *19*(7), 1644–1646. https://doi.org/10.1093/humrep/deh277

Laurent, O., Benmarhnia, T., Milesi, C., Hu, J., Kleeman, M. J., Cockburn, M., & Wu, J. (2019). Relationships between greenness and low birth weight: Investigating the interaction and mediation effects of air pollution. *Environmental Research*, *175*, 124–132. https://doi.org/10.1016/j.envres.2019.05.002

Laurent, O., Wu, J., Li, L., & Milesi, C. (2013). Green spaces and pregnancy outcomes in Southern California. *Health & Place*, *24*, 190–195. https://doi.org/10.1016/j.healthplace.2013.09.016

LaVeist, T. A. (2005). Disentangling race and socioeconomic status: A key to understanding health inequalities. *Journal of Urban Health*, *82*(3), iii26–iii34. https://doi.org/10.1093/jurban/jti061

Lee, A. C. K., & Maheswaran, R. (2011). The health benefits of urban green spaces: a review of the evidence. *Journal of Public Health*, *33*(2), 212–222. https://doi.org/10.1093/pubmed/fdq068

Lee, P.-C., Wu, C.-D., Tsai, H.-J., Tsai, H.-Y., Lin, S.-H., Wu, C.-K., Hung, C.-Y., & Yao, T.-C. (2021). Residential greenness and birth outcomes: Evaluating the mediation and interaction effects of particulate air pollution. *Ecotoxicology and Environmental Safety*, *211*, 111915. https://doi.org/10.1016/j.ecoenv.2021.111915

Lima, S. A. M., Dib, R. P. E., Rodrigues, M. R. K., Ferraz, G. A. R., Molina, A. C., Neto, C. A. P., Lima, M. A. F. de, & Rudge, M. V. C. (2018). Is the risk of low birth weight or preterm labor greater when maternal stress is experienced during pregnancy? A systematic review and meta-analysis of cohort studies. *PLOS ONE*, *13*(7), e0200594. https://doi.org/10.1371/journal.pone.0200594

Liu, D., Kwan, M.-P., & Kan, Z. (2021). Analysis of urban green space accessibility and distribution inequity in the City of Chicago. *Urban Forestry & Urban Greening*, *59*, 127029. https://doi.org/10.1016/j.ufug.2021.127029

Ludwig, J., Sanbonmatsu, L., Gennetian, L., Adam, E., Duncan, G. J., Katz, L. F., Kessler, R. C., Kling, J. R., Lindau, S. T., Whitaker, R. C., & McDade, T. W. (2011). Neighborhoods, Obesity, and Diabetes—A Randomized Social Experiment. *New England Journal of Medicine*, *365*(16), 1509–1519. https://doi.org/10.1056/NEJMsa1103216

Lupien, S. J., King, S., Meaney, M. J., & McEwen, B. S. (2000). Child's stress hormone levels correlate with mother's socioeconomic status and depressive state. *Biological Psychiatry*, *48*(10), 976–980. https://doi.org/10.1016/S0006-3223(00)00965-3

Maas, J., Verheij, R. A., Spreeuwenberg, P., & Groenewegen, P. P. (2008). Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. *BMC Public Health*, *8*(1), 206. https://doi.org/10.1186/1471-2458-8-206

Maas, J., Verheij, R. A., Vries, S. de, Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology & Community Health*, *63*(12), 967–973. https://doi.org/10.1136/jech.2008.079038

Maas, Jolanda, Verheij, R. A., Groenewegen, P. P., Vries, S. de, & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology & Community Health*, *60*(7), 587–592. https://doi.org/10.1136/jech.2005.043125

Maantay, J. (2001). Zoning, equity, and public health. *American Journal of Public Health*, *91*(7), 1033–1041. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1446712/

Matthay, E. C., Hagan, E., Gottlieb, L. M., Tan, M. L., Vlahov, D., Adler, N. E., & Glymour, M. M. (2020). Alternative causal inference methods in population health research: Evaluating tradeoffs and triangulating evidence. *SSM - Population Health*, 10, 100526. https://doi.org/10.1016/j.ssmph.2019.100526

Margerison, C. E., Pearson, A. L., Lin, Z., & Sanciangco, J. (2020). Changes in residential greenness between pregnancies and birth outcomes: Longitudinal evidence from Michigan births 1990-2012. *International Journal of Epidemiology*, *dyaa158*. https://doi.org/10.1093/ije/dyaa158

Markevych, I., Fuertes, E., Tiesler, C. M. T., Birk, M., Bauer, C.-P., Koletzko, S., von Berg, A., Berdel, D., & Heinrich, J. (2014). Surrounding greenness and birth weight: Results from the GINIplus and LISAplus birth cohorts in Munich. *Health & Place*, *26*, 39–46. https://doi.org/10.1016/j.healthplace.2013.12.001

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, *158*, 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Martin J.A., Hamilton B.E., Osterman M.J.K, Driscoll A.K., & Drake P. Births: Final data for 2017. *Natl Vital Stat Rep,* 67, 1–50.

McEachan, R. R. C., Prady, S. L., Smith, G., Fairley, L., Cabieses, B., Gidlow, C., … Nieuwenhuijsen, M. J. (2016). The association between green space and depressive symptoms in pregnant women: moderating roles of socioeconomic status and physical activity. *J Epidemiol Community Health*, *70*(3), 253–259. https://doi.org/10.1136/jech-2015-205954

McMahan, E. A., & Estes, D. (2015). The effect of contact with natural environments on positive and negative affect: A meta-analysis. *The Journal of Positive Psychology*, *10*(6), 507–519. https://doi.org/10.1080/17439760.2014.994224

Michie, S., Abraham, C., Whittington, C., McAteer, J., & Gupta, S. (2009). Effective techniques in healthy eating and physical activity interventions: A meta-regression. *Health Psychology*, *28*(6), 690–701. https://doi.org/10.1037/a0016136

Mitchell, R., & Popham, F. (2008). Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet*, *372*(9650), 1655–1660. https://doi.org/10.1016/S0140-6736(08)61689-X

Moster, D., Lie, R. T., & Markestad, T. (2008). Long-Term Medical and Social Consequences of Preterm Birth. *New England Journal of Medicine*, *359*(3), 262–273. https://doi.org/10.1056/NEJMoa0706475

Morgan Hughey, S., Kaczynski, A. T., Child, S., Moore, J. B., Porter, D., & Hibbert, J. (2017). Green and lean: Is neighborhood park and playground availability associated with youth obesity? Variations by gender, socioeconomic status, and race/ethnicity. *Preventive Medicine*, *95*, S101–S108. https://doi.org/10.1016/j.ypmed.2016.11.024

Morello-Frosch, R., Zuk, M., Jerrett, M., Shamasunder, B., & Kyle, A. D. (2011). Understanding the Cumulative Impacts Of Inequalities In Environmental Health: Implications For Policy. *Health Affairs*, *30*(5), 879–887. https://doi.org/10.1377/hlthaff.2011.0153

Morris, N. (2003). *1 Health, Well-Being and Open Space Literature Review.*

Mowafi, M., Khadr, Z., Bennett, G., Hill, A., Kawachi, I., & Subramanian, S. V. (2012). Is access to neighborhood green space associated with BMI among Egyptians? A multilevel study of Cairo neighborhoods. *Health & Place*, *18*(2), 385–390. https://doi.org/10.1016/j.healthplace.2011.12.002

Ncube C.N., Enquobahrie D.A., Albert S.M., Herrick A.L., & Burke J.G..(2016) Association of neighbourhood context with offspring risk of preterm birth and low birthweight: a systematic review and meta-analysis of population-based studies. *Social Science & Medicine, 153*: 156–64.

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

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

Oakes, J. M. (2004). The (mis)estimation of neighborhood effects: causal inference for a practicable social epidemiology. *Social Science & Medicine*, *58*(10), 1929–1952. https://doi.org/10.1016/j.socscimed.2003.08.004

Oakes, J. M., Andrade, K. E., Biyoow, I. M., & Cowan, L. T. (2015). Twenty Years of Neighborhood Effect Research: An Assessment. *Current Epidemiology Reports*, *2*(1), 80–87. https://doi.org/10.1007/s40471-015-0035-7

Oakes, J. M., & Rossi, P. H. (2003). The measurement of SES in health research: current practice and steps toward a new approach. *Social Science & Medicine*, *56*(4), 769–784. https://doi.org/10.1016/S0277-9536(02)00073-4

Organisation for Economic Cooperation and Development. Low Birthweight (OECD). (2020). https://www.oecd.org/els/family/CO_1_3_Low_birth_weight.pdf

Ogden, C. L., Carroll, M. D., Fryar, C. D., & Flegal, K. M. (2015). Prevalence of obesity among adults and youth: United States, 2011-2014. *NCHS Data Brief*, *219*, 1–8.

Orians, G. H. (1986). Site Characteristics Favoring Invasions. In H. A. Mooney & J. A. Drake (Eds.), *Ecology of Biological Invasions of North America and Hawaii* (pp. 133–148). https://doi.org/10.1007/978-1-4612-4988-7_8

Osypuk, T. L., Tchetgen, E. J. T., Acevedo-Garcia, D., Earls, F. J., Lincoln, A., Schmidt, N. M., & Glymour, M. M. (2012). Differential Mental Health Effects of Neighborhood Relocation Among Youth in Vulnerable Families: Results From a Randomized Trial. *Archives of General Psychiatry*, *69*(12), 1284–1294. https://doi.org/10.1001/archgenpsychiatry.2012.449

Payne, L. L., Mowen, A. J., & Orsega-Smith, E. (2002). An Examination of Park Preferences and Behaviors Among Urban Residents: The Role of Residential Location, Race, and Age. *Leisure Sciences*, *24*(2), 181–198. https://doi.org/10.1080/01490400252900149

Peen, J., Schoevers, R. A., Beekman, A. T., & Dekker, J. (2010). The current status of urban-rural differences in psychiatric disorders. *Acta Psychiatrica Scandinavica*, *121*(2), 84–93. https://doi.org/10.1111/j.1600-0447.2009.01438.x

Pereira, G., Christian, H., Foster, S., Boruff, B. J., Bull, F., Knuiman, M., & Giles-Corti, B. (2013). The association between neighborhood greenness and weight status: an observational study in Perth Western Australia. *Environmental Health*, *12*(1), 49. https://doi.org/10.1186/1476-069X-12-49

Pereira, G., Foster, S., Martin, K., Christian, H., Boruff, B. J., Knuiman, M., & Giles-Corti, B. (2012). The association between neighborhood greenness and cardiovascular disease: an observational study. *BMC Public Health*, *12*(1), 466. https://doi.org/10.1186/1471-2458-12-466

Picavet, H. S. J., Milder, I., Kruize, H., de Vries, S., Hermans, T., & Wendel-Vos, W. (2016). Greener living environment healthier people?: Exploring green space, physical activity and health in the Doetinchem Cohort Study. *Preventive Medicine*, *89*, 7–14. https://doi.org/10.1016/j.ypmed.2016.04.021

Prince, S. A., Kristjansson, E. A., Russell, K., Billette, J.-M., Sawada, M., Ali, A., Tremblay, M. S., & Prud'homme, D. (2011). A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. *International Journal of Environmental Research and Public Health*, *8*(10), 3953–3978. https://doi.org/10.3390/ijerph8103953

Ratnasiri, A. W. G., Parry, S. S., Arief, V. N., DeLacy, I. H., Halliday, L. A., DiLibero, R. J., & Basford, K. E. (2018). Recent trends, risk factors, and disparities in low birth weight in California, 2005–2014: A retrospective study. *Maternal Health, Neonatology and Perinatology*, *4*(1), 15. https://doi.org/10.1186/s40748-018-0084-2

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

Richardson, E. A., Pearce, J., Mitchell, R., & Kingham, S. (2013). Role of physical activity in the relationship between urban green space and health. *Public Health*, *127*(4), 318–324. https://doi.org/10.1016/j.puhe.2013.01.004

Roe, J. J., Thompson, C. W., Aspinall, P. A., Brewer, M. J., Duff, E. I., Miller, D., … Clow, A. (2013). Green Space and Stress: Evidence from Cortisol Measures in Deprived Urban Communities. *International Journal of Environmental Research and Public Health; Basel*, *10*(9), 4086–4103.

Rondó, P. H. C., Ferreira, R. F., Nogueira, F., Ribeiro, M. C. N., Lobert, H., & Artes, R. (2003). Maternal psychological stress and distress as predictors of low birth weight, prematurity and intrauterine growth retardation. *European Journal of Clinical Nutrition*, *57*(2), 266. https://doi.org/10.1038/sj.ejcn.1601526

Rosenthal, L., & Lobel, M. (2011). Explaining racial disparities in adverse birth outcomes: Unique sources of stress for Black American women. *Social Science & Medicine*, *72*(6), 977–983. https://doi.org/10.1016/j.socscimed.2011.01.013

Sander, H. A., Ghosh, D., & Hodson, C. B. (2017). Varying age-gender associations between body mass index and urban greenspace. *Urban Forestry & Urban Greening*, *26*, 1–10. https://doi.org/10.1016/j.ufug.2017.05.016

Sarkar, C. (2017). Residential greenness and adiposity: Findings from the UK Biobank. *Environment International*, *106*, 1–10. https://doi.org/10.1016/j.envint.2017.05.016

Scott, M. M., Dubowitz, T., & Cohen, D. A. (2009). Regional differences in walking frequency and BMI: What role does the built environment play for Blacks and Whites? *Health & Place*, *15*(3), 897–902. https://doi.org/10.1016/j.healthplace.2009.02.010

Squires, G.D., & Kubrin, C.E. (2006). Privileged Places: Race, Residence, and the Structure of Opportunity. Boulder, CO: Lynne Rienner Publishers, Inc.

Stigsdotter, U. K., Ekholm, O., Schipperijn, J., Toftager, M., Kamper-Jørgensen, F., & Randrup, T. B. (2010). Health promoting outdoor environments - Associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. *Scandinavian Journal of Public Health*, *38*(4), 411–417. https://doi.org/10.1177/1403494810367468

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

Stark, J. H., Neckerman, K., Lovasi, G. S., Quinn, J., Weiss, C. C., Bader, M. D. M., Konty, K., Harris, T. G., & Rundle, A. (2014). The impact of neighborhood park access and quality on body mass index among adults in New York City. *Preventive Medicine*, *64*, 63–68. https://doi.org/10.1016/j.ypmed.2014.03.026

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2008). Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology & Community Health*, *62*(5), e9–e9. https://doi.org/10.1136/jech.2007.064287

Sun, Y., Sheridan, P., Laurent, O., Li, J., Sacks, D. A., Fischer, H., Qiu, Y., Jiang, Y., Yim, I. S., Jiang, L.-H., Molitor, J., Chen, J.-C., Benmarhnia, T., Lawrence, J. M., & Wu, J. (2020b). Associations between green space and preterm birth: Windows of susceptibility and interaction with air pollution. *Environment International*, *142*, 105804. https://doi.org/10.1016/j.envint.2020.105804

Taylor, A. F., Kuo, F. E., & Sullivan, W. C. (2002). Views of nature and self-discipline: Evidence from inner-city children. *Journal of Environmental Psychology*, *22*(1–2), 49–63. https://doi.org/10.1006/jevp.2001.0241

Tennessen, C. M., & Cimprich, B. (1995). Views to nature: Effects on attention. *Journal of Environmental Psychology*, *15*(1), 77–85. https://doi.org/10.1016/0272-4944(95)90016-0

Thayamballi, N., Habiba, S., Laribi, O., & Ebisu, K. (2020). Impact of Maternal Demographic and Socioeconomic Factors on the Association Between Particulate Matter and Adverse Birth Outcomes: A Systematic Review and Meta-analysis. *Journal of Racial and Ethnic Health Disparities*. https://doi.org/10.1007/s40615-020-00835-2

Tierney, P. T., Dahl, R., & Chavez, D. (2001). Cultural diversity in use of undeveloped natural areas by Los Angeles county residents. *Tourism Management*, *22*(3), 271–277. https://doi.org/10.1016/S0261-5177(00)00058-3

Tilt, J. H., Unfried, T. M., & Roca, B. (2007). Using objective and subjective measures of neighborhood greenness and accessible destinations for understanding walking trips and BMI in Seattle, Washington. *American Journal of Health Promotion*, *21*(4_suppl), 371–379. https://doi.org/10.4278/0890-1171-21.4s.371

Toftager, M., Ekholm, O., Schipperijn, J., Stigsdotter, U., Bentsen, P., Grønbæk, M., Randrup, T. B., & Kamper-Jørgensen, F. (2011). Distance to green space and physical activity: A Danish national representative survey. *Journal of Physical Activity and Health*, *8*(6), 741–749. https://doi.org/10.1123/jpah.8.6.741

Torres, S. J., & Nowson, C. A. (2007). Relationship between stress, eating behavior, and obesity. *Nutrition*, *23*(11), 887–894. https://doi.org/10.1016/j.nut.2007.08.008

Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., … Nieuwenhuijsen, M. J. (2015). Natural outdoor environments and mental and physical health: Relationships and mechanisms. *Environment International*, *77*, 35–41. https://doi.org/10.1016/j.envint.2015.01.012

Tuan, Y. F. T. (1974). A Study of Environmental Perception. Attitudes, and Values.

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

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

UN World Urbanization Prospects 2018. Population Division. https://population.un.org/Wup/Publications/

US Census Bureau. 2010 Geographic Terms and Concepts - Census Tract. https://www.census.gov/geo/reference/gtc/gtc_ct.html

van den Berg, A. E., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between stressful life events and health. *Social Science & Medicine*, *70*(8), 1203–1210. https://doi.org/10.1016/j.socscimed.2010.01.002

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

Van Renterghem, T., Forssén, J., Attenborough, K., Jean, P., Defrance, J., Hornikx, M., & Kang, J. (2015). Using natural means to reduce surface transport noise during propagation outdoors. *Applied Acoustics*, *92*, 86–101. https://doi.org/10.1016/j.apacoust.2015.01.004

Villeneuve, P. J., Jerrett, M., Su, J. G., Weichenthal, S., & Sandler, D. P. (2018). Association of residential greenness with obesity and physical activity in a US cohort of women. *Environmental Research*, *160*, 372–384. https://doi.org/10.1016/j.envres.2017.10.005

Ward, Z. J., Bleich, S. N., Cradock, A. L., Barrett, J. L., Giles, C. M., Flax, C., Long, M. W., & Gortmaker, S. L. (2019). Projected U.S. state-level prevalence of adult obesity and severe obesity. *New England Journal of Medicine*, *381*(25), 2440–2450. https://doi.org/10.1056/NEJMsa1909301

Wells, N. M., & Evans, G. W. (2003). Nearby Nature: A Buffer of Life Stress among Rural Children. *Environment and Behavior*, *35*(3), 311–330. https://doi.org/10.1177/0013916503035003001

World Health Organization. Urban Green Space Interventions: A Review of Impacts and Effectiveness. Copenhagen: World Health Organization. 2017

Wigginton, N. S., Fahrenkamp-Uppenbrink, J., Wible, B., & Malakoff, D. (2016). Cities are the Future. *Science*, *352*(6288), 904–905. https://doi.org/10.1126/science.352.6288.904

Witten, K., Hiscock, R., Pearce, J., & Blakely, T. (2008). Neighbourhood access to open spaces and the physical activity of residents: A national study. *Preventive Medicine*, *47*(3), 299–303. https://doi.org/10.1016/j.ypmed.2008.04.010

Wohlwill, J. F. (1983). The Concept of Nature. In I. Altman & J. F. Wohlwill (Eds.), *Behavior and the Natural Environment* (pp. 5–37). https://doi.org/10.1007/978-1-4613-3539-9_2

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

Zain, M. M., & Norman, R. J. (2008). Impact of obesity on female fertility and fertility treatment. *Women's Health*, *4*(2), 183–194. https://doi.org/10.2217/17455057.4.2.183

Zimmerman, F. J., & Shimoga, S. V. (2014). The effects of food advertising and cognitive load on food choices. *BMC Public Health*, *14*(1), 342. https://doi.org/10.1186/1471-2458-14-342