ABSTRACT

ZHANG, ZHENZHEN. Creating a Network of Green Infrastructure: The Role of Green Schoolyards in Enhancing Environmental Justice, Promoting Student Engagement and Well-Being. (Under the direction of Katherine L. Martin and Kathryn T. Stevenson).

Access and exposure to nature have been found to provide variety of benefits to children. However, in urban areas, natural settings such as green spaces and urban trees are not equally distributed. Children from low-income and communities of color may have less access and expose to nature. As public schools exist in every community and school attendance is compulsory, green schoolyards can be a promising source for providing equal access to nature and associated benefits for children. This dissertation explores the use of green schoolyards as an approach to provide children with equal access to nature and its benefits by assessing the spatial distribution of greenness across demographic landscape (chapter 2), and by understanding factors that affect children’s usage of nature-based features (chapter 3), and by understanding children’s perception of physical environment of schoolyards (chapter 4).

Chapter 2. There is strong evidence that urban green infrastructure (GI) provides a diverse array of ecosystem services, but that these benefits are unequally distributed, primarily along socioeconomic and racial/ethnic lines. This study evaluated whether GI (i.e. tree canopy cover and total greenness) in public schoolyards is a promising source to mitigate inequities in the distribution of GI and its benefits. The spatial distribution of tree canopy cover and total greenness in schoolyards with those in neighborhood school attendance zones across four school districts in North Carolina was compared, and the relationship between GI and demographics of
schools and neighborhoods were analyzed. Results suggest that GI is more evenly distributed across demographics in schools, but not in neighborhoods. These findings are encouraging, as they suggest that greening schoolyards may be a promising mechanism for mitigating environmental injustices around access to urban GI.

Chapter 3. Greening schoolyards is a promising strategy to promote access to nature and its benefits for all children in urban settings. However, installing a green schoolyard does not guarantee its use. Previous research has investigated how the physical make-up of school grounds, teacher beliefs and behaviors, and even student attitudes predict use of school grounds, but to our knowledge, few have considered them together. This research inventoried 9 urban school grounds and surveying an associated 199 3rd-6th grade elementary students and their teachers (n = 14). Results highlight how students’ awareness and use of nature-rich areas in schoolyards is substantially lower than that of traditional schoolyard features, but that teachers can foster awareness nature-rich areas. Specifically, teachers who take students outdoors or attend professional development training in environmental education have students who are both more aware of and more likely to use natural elements that exist on their school grounds. Further, there is no variation in affinity for woodlands across demographic predictors, suggesting outdoor spaces may be inviting for all children. The findings suggest efforts to green schoolyards in urban environment should integrate teacher professional development and associated engagement with administration to foster the use by teachers and students, and further expand the nature-benefits to serve all children.
Chapter 4. Implementing nature-rich elements in schoolyards may enhance school experiences by connecting children with nature. Previous research provides evidence of green schoolyards can be beneficial to children and communities, but little research explores students’ perceptions about the benefits of schoolyards and how natural elements and the use may shape student experiences. This research examined the relationship between nature-based attributes and nature-based use with students’ perceptions of schoolyards’ benefits to self (e.g. playing, learning) and to the community (e.g. improving air and water quality) across 9 schools in Raleigh, North Carolina (n = 199). In general, students viewed schoolyards in a positive way, and they perceived more benefits to self than community. Regression analyses found that the isolated effect of the presence of nature-based attributes was limited. Instead, the use of nature-based attributes had a stronger effect on students’ positive feelings towards schoolyards. These findings suggest that schoolyard greening efforts should be paired with policies and curricular practices to encourage interaction with nature-based elements to ensure benefits are fully realized by students.
Creating a Network of Green Infrastructure: The Role of Green Schoolyards in Enhancing Environmental Justice, Promoting Student Engagement and Well-Being

by
Zhenzhen Zhang

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Forestry

Raleigh, North Carolina
2021

APPROVED BY:

_______________________________     _______________________________
Dr. Katherine L. Martin                   Dr. Kathryn T. Stevenson
Committee Co-Chair                      Committee Co-Chair

_______________________________     _______________________________
Dr. Joshua Gray                    Dr. Aaron Hipp

_______________________________
Dr. Yuan Yao
DEDICATION

I would like to dedicate this dissertation to my families who are always supportive to my decision, my passion and my life, for my graduate mentors who guide me to be a researcher and conduct this study, and for the future researchers who can use this study as their guide or reference.
BIOGRAPHY

Zhenzhen Zhang received a Bachelor of Science degree in Ornamental Horticulture from Beijing Forestry University in 2014, received a Master of Science degree in Environmental Science and a Master of Landscape Architecture from the University of Michigan in 2017. Since 2017, she began to pursue his Doctor of Philosophy degree in the Department of Forestry and Environmental Resources at North Carolina State University. She is interested in using interdisciplinary knowledge from geography, social science, environmental science and urban planning to address questions related to environmental justice, children-nature and community adaptation.
ACKNOWLEDGEMENTS

I would like to express my thanks to my committee members, my family and friends, and my collaborators for all the support and guidance during my PhD program.

I cannot be more grateful for the mentorship, guidance, and help from my advisor Dr. Katherine Martin who steadily supports me since the very beginning of my program at NCSU. During four years, Dr. Martin provides me supports me to investigate interdisciplinary studies I am interested in. With her support, I am able to build my critical thinking, explore my potential and learn skills. Dr. Martin also mentors me in data and project management, which is beneficial to my future career. Dr. Martin also builds a diverse, inclusive lab environment that supports women and minority students in science.

I also would like to show my great thanks to Dr. Kathryn Stevenson, my co-advisor, who guided me to build network with people, taught me the way to communicate and use the proper language in social science with her amazing research abilities and rich experience in environmental education research.

It is my great honor to have Dr. Yuan Yao as my committee member who guided and advised me with his excellent research and knowledge from industry ecology and sustainability.

I especially want to thank Dr. Joshua Gray for his support in the field of geospatial science and machine learning techniques all the time with his great knowledge and experience.

I also would like to thank Dr. Aaron Hipp for being my committee member and generously providing his help and advice on my dissertation.
Meanwhile, I want to show my gratitude to all my collaborators including teachers from Wake County Public School System, research coordinators from Water Resource Research Institute and staffs from City of Raleigh who have helped me to conduct reach.

I also would like to thank all of my friends, Qianyun Yuan, Amy Wang, Jessica Qu, Yiming Wang, Wenhui Geng, Sipan Liu, Haonan Tong, Chuan Xu, Junwei Li, Elly Gay, Chase Bergeson etc. who have continuously supported me in my work and life.

I truly thank to my parents, Jiyu Shi and Qing Zhang, for strongly and firmly supporting me during my overseas time. Without the encouragement and support from my mother and father, I cannot reach the goal I pursue.
# TABLE OF CONTENTS

LIST OF TABLES ....................................................................................................................... viii  
LIST OF FIGURES ....................................................................................................................... ix  

CHAPTER 1. INTRODUCTION .....................................................................................................1  
1.1 Background (Nature benefit) .............................................................................................1  
1.2 Urban children-nature deficit ..........................................................................................3  
    1.2.1 Urban green infrastructure .....................................................................................4  
    1.2.2 Legacy issue of GI planning and policy .................................................................6  
1.3 Public schools and green schoolyard ...............................................................................7  
    1.3.1 Green schoolyard .....................................................................................................8  
    1.3.2 Challenges .............................................................................................................10  
1.4 Objectives .......................................................................................................................11  

CHAPTER 2. SCHOOLYARDS AS SOURCES OF GREEN EQUITY: UNDERSTANDING SPATIAL AND DEMOGRAPHIC DISTRIBUTION OF URBAN GREEN INFRASTRUCTURE ACROSS FOUR PUBLIC SCHOOL DISTRICTS IN NORTH CAROLINA, USA ..........12  
2.1 Introduction .....................................................................................................................13  
2.2 Methods and Materials ...................................................................................................18  
    2.2.1 Study Area .............................................................................................................18  
    2.2.2 Socioeconomic demographics at public elementary schools and adjacent neighborhoods ..............................................................................................................20  
    2.2.3 Land cover classification ......................................................................................22  
    2.2.4 Statistical analyses ...............................................................................................24  
2.3 Results ............................................................................................................................26  
    2.3.1 Demographics in schools and adjacent neighborhoods .........................................26  
    2.3.2 Land cover in schools and adjacent neighborhoods ............................................27  
    2.3.3 Statistical results ..................................................................................................30  
2.4 Discussion .......................................................................................................................33  
2.5 Limitation and Future Research .....................................................................................37  
2.6 Conclusion ......................................................................................................................37  

CHAPTER 3. EXPLORING GEOGRAPHICAL, CURRICULAR, AND DEMOGRAPHIC FACTORS OF NATURE USE BY CHILDREN IN URBAN SCHOOLYARDS IN RALEIGH, NC, USA .................................................................................................................................40  
3.1 Introduction .....................................................................................................................41  
3.2 Methods ..........................................................................................................................47  
    3.2.1 Study sites .............................................................................................................47  
    3.2.2 Survey data collection ..........................................................................................48  
    3.2.3 Survey instrument ...............................................................................................50  
    3.2.4 Data analysis ........................................................................................................52  
3.3 Results ...........................................................................................................................53
3.3.1 Green spaces in schoolyards and corresponding awareness ........................................53
3.3.2 Descriptive statistics for outdoor activities .................................................................54
3.3.3 Regression models ......................................................................................................56
3.4 Discussion .......................................................................................................................59
3.4.1 The presence of green spaces in schoolyards .............................................................59
3.4.2 The awareness and the use of green spaces in schoolyards .........................................60
3.4.3 Limitations and future study .......................................................................................65
3.5 Conclusion and Recommendations ..............................................................................66
CHAPTER 4. USE OF NATURE-BASED SCHOOL GROUNDS CAN ENHANCE STUDENTS’
PERCEPTIONS OF SCHOOLYARD BENEFITS ........................................................................68
4.1 Introduction .....................................................................................................................68
4.2 Methods ..........................................................................................................................73
4.2.1 Schools and Participants ............................................................................................73
4.2.2 Survey instrument ......................................................................................................75
4.2.3 Data analysis ..............................................................................................................77
4.3 Results ............................................................................................................................78
4.4 Discussion .......................................................................................................................80
CHAPTER 5. CONCLUSIONS AND FUTURE RESEARCH ......................................................85
REFERENCES .......................................................................................................................86
APPENDIX ..........................................................................................................................108
APPENDIX A. CHAPTER 2. SUPPORTING INFORMATION .................................................109
APPENDIX B. CHAPTER 3. SUPPORTING INFORMATION ................................................113
APPENDIX C. CHAPTER 4. SUPPORTING INFORMATION ................................................122
LIST OF TABLES

Table 2.1 The average of demographics statistics (SD) at the school and neighborhood (school attendance zones) scales across the urban portion of school districts and the rate of tree canopy cover and total green infrastructure, GI (SD). .................................................................27

Table 2.2 Spearman’s correlation results of tree canopy cover (tree canopy cover), total GI (total green infrastructure) and 1. school-level measures of socioeconomic status (free and reduced lunch population; FRL) and People of Color (students identifying as people of color) as well as 2. neighborhood measures of socioeconomic status (SVI SES) and people of color (SVI race/ethnicity). .............................................................................30

Table 2.3 OLS and SLAG for tree canopy cover, total green infrastructure, GI, and demographics in schools including socioeconomic status (free and reduced lunch population; FRL) and People of Color (students identifying as people of color). .........................................................32

Table 2.4 OLS and SLAG models for tree canopy cover, total green infrastructure, GI, and demographics in neighborhoods, including measures of socioeconomic status (SVI SES) and peoples of color (SVI race/ethnicity). .....................................................................33

Table 3.1 Demographics of teachers and students who finished survey. Data is displayed in percentage .....................................................................................................................50

Table 3.2 School information including the number of students and teachers participated in the survey from each school and the presence of green spaces information in schools (1 = exist, 0 = no). .................................................................................................................54

Table 3.3 Predictors of the awareness of green space types in schoolyards among students (n = 199), including a nested random effect for teachers in generalized regression model.57

Table 3.4 Factors of activities among students, including a nested random effect for teachers. ...58

Table 4.1 Summary of students (N = 199) and teacher (N = 14) participants for the survey ........75

Table 4.2 Students’ perceived benefits summary statistics with a broader benefits category from the factor analysis (n = 199) .................................................................................................................79

Table 4.3 Regression models predicting benefits to self and benefits to the community as a function of schoolyards’ attributes and use, controlling students’ demographic (n = 199), including a nested random effect for teachers. ..................................................................................80
LIST OF FIGURES

Figure 2.1 Elementary schools (black polygons) and neighborhoods (school attendance zones, colored polygons) within urban boundaries.................................................................19

Figure 2.2 Zoomed in examples of schools’ and neighborhoods’ (school attendance zones) land cover in the four school districts..................................................................................28

Figure 2.3 Spatial distribution of tree canopy (tree canopy cover), total GI (total green infrastructure) and SVI for socioeconomic (SES) and race/ethnicity in neighborhoods (school attendance zones). ............................................................................................................29

Figure 3.1 Four green space types measured in schoolyards.................................................................52

Figure 3.2 Frequency of students’ self-report activities in their schoolyards by gender, race/ethnicity and grade, coded in 1-5 scale (Never, Once or twice a year, About once a month, About once a week, Several times a week) with 95% confidence interval...55

Figure 4.1 Nature-based attributes in schoolyards..................................................................................74
CHAPTER 1. INTRODUCTION

1.1 Background (Nature benefit)

Exposure and access to nature provides a host of benefits and links to the quality of life (Ward Thompson, Roe, & Aspinall, 2013). These benefits include but not limited to physical health outcomes such as reduced blood pressure (Li et al. 2011), lowered blood glucose levels (Ohtsuka, Yabunaka, & Takayama, 1998), reduced cortisol levels and pulse rate (Lee et al. 2011), as well as mental health benefits such as positive moods (Bratman, Hamilton, & Daily, 2012), restored attention (Berman, Jonides, & Kaplan, 2008) and improved cognitive function (Bratman, Daily, Levy, & Gross, 2015). Access to nature also provides social and cultural benefits (Bratman et al., 2019) by supporting social interaction and cohesion, enhancing community attachment and developing a sense of place (Arnberger & Eder, 2012; Jennings & Bamkole, 2019; McCunn & Gifford, 2014). The outcome of access to nature cannot be hindered even with the control of physical activity types (e.g., walking, running, viewing etc.) (Bowler, Lisette, Knight, & Pullin, 2010). For example, people reported lower anxiety and depression and higher vigor after walking in forest compared to walking in urban environment (Takayama et al., 2014). Similarly, other research also found that self-reported emotions were more positive in natural environment than urban settings (Bodin & Hartig, 2003; Hartig, Evans, Jamner, Davis, & Gärling, 2003) and positive impact on immune system associated with nature but not cities (Q Li et al., 2008). Although the impact from nature may be limited compared to structural characteristics such as income, education level and employment status, the positive outcomes
associated with nature cannot be ignored as a small contribution on a large population is profound (Hartig, Mitchell, De Vries, & Frumkin, 2014).

Access to nature can be particularly important for children, as childhood is the foundation for healthy adulthood. One well-documented benefit is physical health outcome. Research has found that natural environment can stimulate physical activities of children (Dyment & Bell, 2008; Sharma-Brymer & Bland, 2016; van Dijk-Wesselius, Maas, Hovinga, van Vugt, & van den Berg, 2018), which is positively associated to enhancement in metabolism, cardiorespiratory fitness and skeletal health that may influence adult health status (Ortega, Ruiz, Castillo, & Sjöström, 2008). For example, research found that green spaces have the potential to promote physical activities, especially moderate and light activities such as non-competitive play, and open-ended forms of play (Dyment & Bell, 2008). Nature may also offer health and support for children’s development beyond physical activity. Compared to conventional outdoor fields that designed for vigorous physical activities (e.g., running and competitive sports), spaces with natural features support diverse play for children at different ages and with varying competencies, (Herrington & Brussoni, 2015). For instance, children can develop more diverse and creative play in natural environment compared to spaces with fewer natural settings (Fjørtoft, 2004; Herrington & Brussoni, 2015; Moore, 2014). Children are able to use natural feature to conduct unstructured play (Tillmann, Button, Coen, & Gilliland, 2019). These unstructured and free play with nature may stimulates motor development (Fjørtoft, 2001), problem solving skills (Burdette & Whitaker, 2005) and social interaction within peers
Research has found that nature boosts psychological health to a greater extent than physical activities in other environment (Mitchell, 2013). The synergy between psychological benefits and nature also exist in childhoods. These benefits include restoring children’s attention function (Kuo & Taylor, 2004; Taylor, Kuo, & Sullivan, 2001), improving cognitive function (Keeler et al., 2019), and reducing stress and mental fatigue (D. Li & Sullivan, 2016; Tyrväinen et al., 2014). For instance, children with attention deficit disorder were able to manage their attention better after playing in green settings compared to playing in either indoor or outdoor with non-green settings (Taylor et al., 2001). Similarly, research found that children concentrated better after walking in a park than walking in other urban areas (Taylor & Kuo, 2009). Aside from the direct contact, indirect contact with nature such as visual access to natural environment also supports mental health. For example, green window views can enhance children’s performance and concentration (Taylor, Kuo, & Sullivan, 2002). Other research also found that green window views help restore attention and support recovery from stress in high school students (D. Li & Sullivan, 2016).

1.2 Urban children-nature deficit

Although nature provides a host of benefits, urbanization limits people’s contact with nature, certainly including children who live in urban environments (McCurdy, Winterbottom, Mehta, & Roberts, 2010). Compared to previous generations, children spend less time in nature.
Increased screen time is a major cause of the declined time in nature. A 2011 study showed that over 50% of Canadian youth in grades 6 to 12 spent more than two hours in screen-based activities such as watching TV and playing video games (Leatherdale & Ahmed, 2011). Recently, the expanding ownership of personal smart phone and access to internet provide another way for screen-based activities among children (Rideout & Robb, 2019). A study focusing on rural youth found that children in grades 6 to 8 spent about 2 hours on electronic media but spent 30 min less in outdoor nature (Larson et al. 2019). Considering the fact that rural children are more convenient to access nature, we can assume that the nature-deficit is more prominent across urban children. Further, some children maybe more attracted by physical activities such as biking and jogging or land-based sports (Larson, Green, & Cordell, 2011). These activities may be outdoors, but since they are not specifically focusing on time spending in nature, some of the benefits associated with nature may be reduced.

1.2.1 Urban green infrastructure

The natural components in urban environments, which we refer as urban green infrastructure (UGI) are increasingly recognized as resources to connect people with nature, beneficial to environmental, physical, and mental health as the planet rapidly urbanizes (Benedict & McMahon., 2002). Especially in urban areas, where built-up features are dominant, exposure and access to UGI such as urban parks and forests can ensure ecosystem services be delivered to benefit individuals and communities. These benefits range from individual recreational and
educational opportunities (Calderón-Contreras & Quiroz-Rosas, 2017), individual health outcomes such as reduced stress (Ward Thompson et al., 2012) and improved cardiovascular health (Keeler et al., 2019) to community-level benefits such as regulating urban stormwater (Berland et al., 2017), mitigating urban heat and pollution (Dobbs, Nitschke, & Kendal, 2014) and stimulating community cohesion (Peters, Elands, & Buijs, 2010). Many benefits to children via access and exposure to UGI, including increased physical activity (Dyment, Bell, & Lucas, 2009), relief from depression (Chawla, Keena, Pevec, & Stanley, 2014), enhanced connectedness to nature (Laaksoharju & Rappe, 2017), as well as better academic performance (Kuo, Browning, Sachdeva, Lee, & Westphal, 2018) and pro-environmental behaviors (Stevenson, Peterson, Bondell, Mertig, & Moore, 2013) have been demonstrated in literature.

Although the nature benefits is well documented, the access and exposure to UGI is not equitable. Low-income communities and people of color have access to UGI with lower quality, maintenance and safety than more privileged groups (Baró, Camacho, Pérez Del Pulgar, Triguero-Mas, & Anguelovski, 2021; Rigolon, 2016; Rigolon, Browning, & Jennings, 2018). For instance, the distribution of tree canopy cover is positively correlated with household income (Schwarz et al., 2015). Similarly, although minority people may live closer to parks, they usually have less access to high quality urban parks that have more amenities, better maintenance and easy access (Rigolon, 2016). Troublingly, low-income and minority communities may suffer some health disparities such as depression, stress, and cardiovascular disease which can be addressed by many benefits associated with UGI and nature (Bates, Bohnert, & Gerstein, 2018;
Mitchell & Popham, 2008; Mitchell, Richardson, Shortt, & Pearce, 2015). For example, African Americans have higher mortality rates from heart disease, cancer, stroke, diabetes etc. than whites (Williams & Mohammed, 2009). This health disparity is also common among children (Reiss, 2013). Low-income family children tend to have worse health status (Reiss, 2013), higher incidence of behavioral problems (Manly, Oshri, Lynch, Herzog, & Wortel, 2013) and increasing mental health problems (Manly et al., 2013). Children from low-income and minority communities have higher risks for behavior and health problems, whereas UGI can be a buffer for children who suffer health inequities by promoting positive development outcomes (Bates, Bohnert, and Gerstein 2018). Accordingly, the uneven distribution of UGI may hinder nature outcomes to children may benefit most from it (McCurdy et al., 2010).

1.2.2 Legacy issue of GI planning and policy

The unequal distribution of GI can be a legacy issue of planning and policy and a result of complex interaction between socioeconomic, demographics and environmental factors (Dobbs et al., 2014). For example, the distribution of contemporary urban forest and species composition in the United States were influenced by the urban parks and civic beautification movements from mid-1800s to early 1900s (Roman et al., 2018). During that period, newly built urban parks, arboreta, and botanical gardens contributed the UGI form at the municipal scale, while decentralized settlements in urban core, sprawling suburban and neighborhood design (e.g., single-family homes) influence patterns of private trees (Roman et al., 2018). Historically,
redlining, a racial discriminatory housing policy, which ranked the perceived risk of investing also affect tree canopy cover at the neighborhood scale. In areas formerly marked as red, where most racial and ethnic minorities used to live, tree canopy cover was much lower than areas characterized by white population (Locke et al., 2021). Socioeconomic status has also affected the pattern of UGI. For example, research has observed a trend of vegetation-income relationship between 1970 and 2000 in the city of Phoenix, Arizona (Jenerette, Harlan, Stefanov, & Martin, 2011). The unequal distribution of UGI creates issues of environmental injustice, where nature benefits are disproportionately distributed to those of higher socioeconomic status and dominant racial groups, and the negative environmental consequences of urbanization disproportionately impact low income, racial/ethnic marginalized residents and their children (Rigolon, 2016).

1.3 Public schools and green schoolyard

Public school systems as a municipal unit, present important stakeholders that have the capacity to adopt UGI in schoolyards, expand nature benefits to children and potentially address the disparities of UGI and its benefits (Stevenson et al., 2020). First, there is a space for greening school ground and installing natural features. Public school properties include a significant amount of impervious surface area. For example, about 32% of school property is impervious surface in the City of Raleigh (UNC Environmental Finance Center, 2018), representing an opportunity for UGI implementation. Second, each school district is a single stakeholder with the potential to make a big impact by creating UGI network without having to coordinate heavily
across sectors. Third, because education is compulsory for children, UGI in schools may provide long-term benefits for healthy adulthoods (Ortega et al., 2008). Fourth, public schools exist in every community. As the distribution of public schools is less tied to sociodemographic factors compared to other amenities such as urban parks (Daï, 2011; Rigolon et al., 2018) and school attendance may draw from different areas to increase student diversity, school has the opportunity to mitigate disparities of UGI by means of greening schoolyards. Last, benefits associated with UGI in schoolyards may be realized by broader communities by serving a source of public green spaces (Bates et al., 2018), and improving overall environmental quality and community welling (Flax, Korthals Altes, Kupers, & Mons, 2020; Iojă, Grădinaru, Onose, Vânău, & Tudor, 2014).

1.3.1 Green schoolyard

As children spend a large proportion of time in schools, schoolyards can play an important role as the place for children to access nature (Akoumanaki-Ioannidou, Paraskevopoulou, & Tachou, 2016). Compared to traditional schoolyards, in which paved areas or covered by turf with scattered trees are most common (Dyment & Bell, 2008; Lindemann-Matthies & Köhler, 2019), green schoolyards are full field with diverse natural settings such as gardens, natural play areas, outdoor classrooms and trails. Noticing the essential role that nature plays for children, more and more schools are starting nature initiatives and there is a growing green schoolyard movement across the US and other countries/regions. For example, San
Francisco Unified School District Green Schoolyard Program that supports design outdoor classroom, gardens, natural play, and tree planting activities has helped over 90% schools within district adopt green schoolyard elements on campus (San Francisco Public Schools, 2017). In Chicago, Space to Grow helps schools make transformations which prioritize outdoor learning, community engagement, solving stormwater issues using special design elements (Space to Grow, 2016). At the national level, the Schoolyard Habitat Program has assisted 10,000 schools to restore and create habitat on school grounds which serve as outdoor classrooms (U.S. Fish and Wildlife Service, 2018).

Green schoolyards are designed with multi-functional and nature-filled green spaces for children to play, learn and explore during school time and provide communities with access to nature and its benefits after hours (Stevenson et al., 2020). Aside from the mental, physical, and social benefits associated with natural settings listed above, UGI in schoolyards may provide academic outcomes. For instance, higher vegetation cover surrounding schools (Leung et al., 2019) and higher tree canopy cover at schools (Kuo, Browning, Sachdeva, et al., 2018; Kweon, Ellis, Lee, & Jacobs, 2017a) is positively associated with math and English tests. Many researchers highlights the value of natural settings that supports inquiry-based learning, place-based learning and interdisciplinary instruction (Acharya, 2018; Barfod & Daugbjerg, 2018; Chawla & Derr, 2012; Guerrero & Reiss, 2020). Since school attendance is compulsory in the United States and many other regions around the world (UNESCO, 2015), green schoolyards can be the source for equal access to nature and its benefits for all children.
1.3.2 Challenges

Green schoolyards have the potential for providing equal access to nature and its benefits. However, there are some challenges in greening schoolyards process. Lacking funding, lacking stable partnership and the difficulty of the maintenance of UGI (UNC Environmental Finance Center, 2018). There is a strong need to look for cross-sector support by highlighting other benefits associated with UGI (e.g., academic learning, student well-being) to provide justification as well as opportunities for partnership (e.g., public health, curricular support from within districts). One key step in building cross-sector support for UGI in schools is to understand what currently exists on school ground as well as the use and preferences of students.

Regarding UGI on school grounds, some studies quantified the green cover (Baró et al., 2021; Schulman & Peters, 2008), other studies examined the specific UGI at school scale and the preference of children (Raith, 2017; van Dijk-Wesselius et al., 2018). Other studies documented the benefits associated with green schoolyards on students (D. Li & Sullivan, 2016; Parmer, Salisbury-Glennon, Shannon, & Struempler, 2009; Plaka & Skanavis, 2016). There are limited studies that examines (1) the UGI on school ground in relationship with sociodemographic factors, (2) these benefits together with the goal of building cross-sector support for UGI around potential dual benefits. By coupling these potential benefits within a single study, results could shed light on ways to implement UGI that optimizes benefits for both municipalities (i.e., stormwater management) and students (i.e., learning and well-being).
1.4 Objectives

The overall objective is to explore the opportunity of urban green schoolyards for equal access to nature, and to understand how the placing UGI in schoolyards improve children’s use of nature and access its benefits. Specifically, we addressed the following research questions: 1. Do schools enhance or mitigate inequities in children’s exposure to GI? 2. What factors affect children play in nature-rich areas rather than traditional outdoor places in schoolyards? 3. Does greening schoolyards improve students’ perceptions of the benefits of schoolyards?

In Chapter 1, we reviewed the current literature related to UGI and associated benefits to children, UGI distribution disparities, and the opportunities and barriers of green schoolyards as source to connect children and community to nature. In Chapter 2, we assessed the UGI distribution across four school districts and in multiple demographic contexts in North Carolina, USA. In Chapter 3, we explored how often students use natural features in urban school grounds for nature-based activities, and factors that influence the use. In Chapter 4, we examined how the physical make-up of urban school grounds (e.g., presence of nature-based attributes) and use by students shapes how students view their own schoolyards. In Chapter 5, we present the conclusions and potential future research.
CHAPTER 2. SCHOOLYARDS AS SOURCES OF GREEN EQUITY: UNDERSTANDING SPATIAL AND DEMOGRAPHIC DISTRIBUTION OF URBAN GREEN INFRASTRUCTURE ACROSS FOUR PUBLIC SCHOOL DISTRICTS IN NORTH CAROLINA, USA

Zhenzhen Zhang, Katherine L. Martin, Kathryn Stevenson, Yuan Yao

Abstract

Green infrastructure (GI) provides a suite of ecosystem services that are widely recognized as critical to health, well-being, and sustainability on an urbanizing planet. However, the distribution of GI across urban landscapes is frequently uneven, resulting in unequal delivery of these services to low-income residents or those belonging to underserved racial/ethnic identities. While GI distribution has been identified as unequal across municipalities, we investigated whether this was true in public schoolyards within and among urban school districts. We examined schoolyards in four metropolitan areas of diverse socio-economic and demographic compositions in North Carolina, USA to determine if they provided equal exposure to GI, then compared whether this was true of the broader urban landscape. We first classified the land cover of elementary schoolyards and their neighborhoods, then used bivariate and multivariate approaches to analyze the relationships between GI (i.e. tree canopy cover and total GI) and the socioeconomic status and race/ethnicity of the schools and surrounding neighborhoods, respectively. We found that the extent of tree canopy cover and total GI in schoolyards was unrelated to the socioeconomic status and the race/ethnicity of students across the four school districts. In contrast, neighborhoods with lower socioeconomic status and larger populations of underserved race/ethnicity residents had less tree canopy cover and total GI. Although total GI was more evenly distributed in schoolyards, the extent of tree canopy cover and total GI in
schoolyards was lower than that in the neighborhoods. This suggests opportunities for school
districts to expand GI in schoolyards, leveraging their potential to increase ecosystem services to
all children, from increased educational opportunities to improved mental, physical, and
environmental well-being.

2.1 Introduction

Urban development has improved quality of life in many aspects, but comes with
tradeoffs in environmental quality (Campbell, 1996). Components of the built environment (e.g.
buildings and pavement) compete with natural elements for urban spaces (Cadenasso, Schwarz,
& Pickett, 2007). Concepts like green (Kahn, 2007) and sustainable cities highlight the value of
green space (e.g. urban parks and forest) in the built matrix for resident wellbeing (Keeler et al.,
2019). The natural components in urban environments, which we refer to as urban green
infrastructure (GI), are increasingly recognized as beneficial to environmental, physical, and
mental health as the planet rapidly urbanizes.

GI can be defined in multiple ways. Here, we define GI to include a broad suite of green
space types and natural areas such as greenways (i.e., protected corridors), parks, urban forests,
and woodlands (Benedict & McMahon., 2002, 2006; Conway, Khan, & Esak, 2020; Meerow &
Newell, 2017), which provide a range of ecosystem services for urban environments (Bolund &
Hunhammar, 1999; Keeler et al., 2019; Seiwert & Rößler, 2020). In this broad interpretation,
most GI types provide some degree of ecosystem service regulation, including mitigation of
stormwater, urban heat, and pollution (Dobbs et al., 2014). In addition, GI types such as urban
forests and wetlands provide supporting services such as wildlife habitat (Angold et al., 2006;
Baró et al., 2016). Most GI types also provide interlinked cultural ecosystem services. For
instance, bio-retention ponds and rain gardens not only assist with stormwater management, but also provide cultural services such as aesthetics and educational opportunities (Bolund & Hunhammar, 1999; Calderón-Contreras & Quiroz-Rosas, 2017; Keeler et al., 2019).

Among GI types, trees in particular provide an array of ecosystem services (Dobbs et al., 2014). Trees support regulating services for noise reduction, pollution absorption (Bolund & Hunhammar, 1999), and urban heat island mitigation (Ziter, Pedersen, Kucharik, & Turner, 2019). Trees also provide mental and physical health benefits by connecting people to nature, such as providing green window viewscapes, which have been shown to mitigate symptoms of attention-deficit disorder (Kuo & Taylor, 2004). Furthermore, trees bolster the performance of other GI, such as enhancing green space stormwater mitigation by increasing infiltration and evapotranspiration (Keeler et al., 2019).

Although GI provides important ecosystem services, GI is often lacking where residents are low-income or members of underserved or minority racial or ethnic identities, suggesting some disparity with the respect of the ecosystem services provided by GI (Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Wolch, Byrne, & Newell, 2014). The spatial distribution of GI has been well-documented as an environmental justice concern in the literature (Gerrish & Watkins, 2018). Here, we apply a definition of environmental justice expanded from the initial focus on the burdens of environmental hazards to include the unequal distribution of environmental benefits, including ecosystem services (Boone, 2008). Under this definition, the spatial distribution GI is frequently used as a proxy to identify concerns about the distribution of environmental benefits or ecosystem services provided by GI (Riley & Gardiner, 2020). For example, across cities, trees tend to be positively correlated with higher income (X. Li, Zhang, Li, Kuzovkina, & Weiner, 2015; Schwarz et al., 2015) while negatively correlated with
populations of people of color (Schwarz et al., 2015). In a survey of over 5,000 municipalities, McDonald et al., (2021) found that low-income census blocks had 15.2% less tree canopy cover and were 1.5°C hotter than higher income census blocks. Similarly, immigrants, Peoples of Color, and residents of low socioeconomic status (SES) tend to live further from urban green space like parks (Rigolon, 2016). This inequality in GI distribution raises environmental justice concerns because the ecosystem services provided by green space would therefore be disproportionately distributed to those of higher SES and dominant identity groups, and the negative environmental consequences of urbanization disproportionately impact low income residents and those of underserved race/ethnicity identities (Rigolon, 2016; Rigolon et al., 2018).

The unequal distribution of GI can be attributed to legacy issues in urban planning and policy, and also as a result of complex interactions between multiple social and economic factors (Dobbs et al., 2014). For example, the distribution and species composition of contemporary urban forests in the United States (US) are shaped by the urban parks and civic beautification movements from mid-1800s to early 1900s (Roman et al., 2018). SES has historically also been positively correlated with tree distribution. Jenerette et al., (2011) found that over time (from 1970-2000), tree cover became increasingly concentrated in neighborhoods with higher income in Phoenix, Arizona.

In the US, public school systems have the capacity to mitigate some of the inequality in GI distribution, in part because they governed at municipal or county levels, which could reduce institutional barriers in adopting greening across municipalities (Iojâ et al., 2014). Public schools are also often one of the largest landowners in a municipality. For example, the New York City Department of Education is among the top ten landowners overall in New York City (Bilogur, 2016; NYC Department of City Planning, 2020). Efforts could be focused on a single agency
that is positioned to make a big impact without having to coordinate heavily across sectors. Public school properties also represent an opportunity for GI implementation, as they currently tend to include a significant amount of impervious surface. For example, public schools in the city of Raleigh, North Carolina, occupy 5.85 km$^2$ of land, 32% of which is impervious surface (12% buildings, 20% roads and parking lots) (NC One Map, 2021; UNC Environmental Finance Center, 2018). School systems therefore represent a single stakeholder that is both a significant contributor to challenges created by the built environment and a potential partner to create a significant GI network throughout the built environment.

Perhaps most importantly, schools have the opportunity to provide GI benefits to a population that may receive long-term benefits from it. Nearly all children between ages 5-18 spend a significant portion of their days at schools (Ozdemir & Yilmaz, 2008), and placing GI in schoolyards can benefit both students and staff (Kerlin, Santos, & Bennett, 2015). Children have shown to benefit from exposure to GI, such as having increased physical activity (Ozdemir & Yilmaz, 2008), decreased stress (Chawla et al., 2014), and increased connection to nature (Laaksoharju & Rappe, 2017). In addition to these benefits, green schoolyards can offer ecosystem services benefiting the broader community by providing public green space (Bates et al., 2018), improving air quality, regulating temperature and stormwater, and contributing to safer and better living environments (Calderón-Contreras & Quiroz-Rosas, 2017; Flax et al., 2020; Iojă et al., 2014).

As a type of GI in schoolyards, trees in particular provide important benefits to children. Schools with more trees are associated with better Math and Reading performance (i.e. test scores) (Kweon, Ellis, Lee, & Jacobs, 2017b; Sivarajah, Smith, & Thomas, 2018), as well as a higher graduation rate (Matsuoka, 2010). The positive association between trees in schoolyards
and academic performance has also been found in schools with high poverty rates (Kuo, Browning, Sachdeva, et al., 2018). Trees in and near schoolyards are more strongly associated with better academic performance than trees in neighborhoods (Kuo, Browning, Sachdeva, et al., 2018; Kuo, Klein, Browning, & Zaplatosch, 2021). In addition, trees can provide unexpected benefits. For example, forested areas of schoolyards can provide materials for self-initiated, place-based play activities such as using branches as hammers and construction materials, thus allowing children to use trees for playing, relaxing and shading, while at the same time developing creativity and building friendship with peers (Laaksoharju & Rappe, 2017).

Moreover, trees form the in-between spaces nearby sports fields and playgrounds (Aminpour, Bishop, & Corkery, 2020), though, without specific designed functions, children can use these spaces with overhead trees for refuge, group play (e.g. Hide and Seek games) and self-direct play (Aminpour et al., 2020).

Although children have opportunities to access GI benefits both in and outside schools (Kuo, Browning, Sachdeva, et al., 2018), evidence would suggest that their access to GI outside school is likely to be affected by the socioeconomic status and racial/ethnic make-up of their neighborhoods. As highlighted above, low-income neighborhoods and racial and ethnic minority neighborhoods often have less access to GI than their higher income or white counterparts (Astell-Burt, Feng, Mavoa, Badland, & Giles-Corti, 2014; Rigolon, 2016). What is not well understood is whether the GI inequity documented across cities is also present in public schoolyards. As the physical distribution of schools is less tied to economics compared to other amenities (e.g., parks: Rigolon, 2016, transportation: Bullard, 2003Bullard, 2003), and school attendance may draw from different areas to increase student diversity, there is potential for GI on school grounds in the form of green schoolyards to mitigate disparities of GI and its benefits.
This study aimed to understand the distribution of GI across four school districts and in multiple demographic contexts in North Carolina. Our central questions were: Is GI in schoolyards correlated with the school demographics? Are these relationships different than in areas outside of schoolyards? We addressed this question by analyzing both total green infrastructure (total GI) as well as tree canopy cover specifically, given the particular benefits provided by trees, across the urban portion of four school districts. We first compared tree canopy cover and total GI across student demographic data available from the schools. Then, to determine if land cover-demographic correlations were different in schoolyards compared to surrounding areas, we compared total GI and tree canopy cover in neighborhoods (represented by school attendance zones, approximately 10 km², as described below) to the SES and race/ethnicity demographics of the neighborhoods.

2.2 Methods and Materials

2.2.1 Study Area

We selected four county-wide school districts across North Carolina: Cumberland, Forsyth, Mecklenburg and Wake, representing four of the five most populated counties in the state and among the largest 100 school districts in the US (Figure 2.1). These four school districts are located in the Southern Appalachian Piedmont physiographic region, where the mean temperature is 26.1 °C in July and 4.3 °C in January, with a mean annual precipitation of 1100 mm (Taverna, Peet, & Phillips, 2005). The common trees are Oak species (Quercus sp.), Hickories (Carya sp.), Red Maple (Acer rubrum), and Loblolly pine (Pinus taeda) (M. J. Brown, 2018).
We focused on elementary schools (primarily between 6–11 years old) because outdoor education activities are more frequent in elementary schools (Martin, 2003) and elementary school children have more outdoor time during the school day compared to higher grade students (Pagels et al., 2014). We further narrowed our study sites to elementary schools within the urban boundaries of the four districts. The boundary of urban areas is determined as “densely settled core of census tracts and/or census blocks with a minimum of 50,000 or more people, along with adjacent territory containing non-residential urban land uses and territory with low population density” (US Census Bureau, 2010). This demarcation of urban boundaries resulted in 97 out of 116 district elementary schools from Wake County Public Schools (the city of Raleigh and
surrounding municipalities, “Raleigh”), 91 out of 110 elementary schools in Mecklenburg County Public Schools (the city of Charlotte), 42 out of 52 elementary schools in Cumberland County Public Schools (the city of Fayetteville), and 36 out of 36 elementary schools in Forsyth County Public Schools (the city of Winston-Salem). We did not exclude any school type specifically (e.g., schools with special education programs are also included). As our study focuses on GI in schoolyards in the temperate deciduous region, it may be important to understand that most schools are open in spring and fall with a summer break; although there are some year-round schools. Currently, there are 34 elementary schools in Raleigh (WCPSS, 2020c) and 2 elementary schools in Fayetteville (Cumberland County Schools, 2020) that are year-round.

2.2.2 Socioeconomic demographics at public elementary schools and adjacent neighborhoods

Demographics in schools

At the schoolyard level, we collected demographic information including race/ethnicity and the percent of students eligible for free and reduced lunch (FRL) as an indicator of SES (Nicholson, Slater, Chriqui, & Chaloupka, 2014) from the National Center for Education Statistics (US Department of Education [USDE], 2019). We created a consolidated race/ethnicity variable, Peoples of Color, for each school population by combining the students identifying as Black, Hispanic, American Indian/Alaska Native, Asian, Native Hawaiian/Pacific Islander, or two or more race/ethnicities. Although we acknowledge grouping these diverse racial and ethnic groups into a single category can be socially problematic and some races/ethnicities may be marginalized altogether (Perea, 1997), we chose this approach because at the neighborhood scale, we used the multivariate Social Vulnerability Index (SVI) from the US Centers for Disease
Control and Prevention that consolidated similar categories of race/ethnicity (Flanagan, Gregory, Hallisey, Heitgerd, & Lewis, 2011).

Demographics in adjacent neighborhoods

We used SVI (Centers for Disease Control and Prevention (CDC), 2018) as the socio-demographic characteristics of neighborhoods which is one of many multi-criteria social vulnerability indices that incorporate census data on metrics including income, education, and race/ethnicity/language. Here, social vulnerability refers to the socioeconomic and demographic factors that affect the resilience of communities (Flanagan et al., 2011). Social vulnerability indices can be constructed in multiple ways, including through the use of census data, stakeholder interviews, or a combination (Cutter, Boruff, & Shirley, 2003; Flanagan et al., 2011). Originally, social vulnerability indices were used to assess community sensitivity to natural hazards, and the capacity of communities to respond, cope, and recover from hazards (Cutter et al., 2003). Such indices also show promise to assess community vulnerability to the hazards of climate change, including stormwater runoff and flooding (Saia et al., 2019). In our study, we used CDC’s 2018 SVI as the socio-demographic characteristics of neighborhoods (Flanagan et al., 2011). We focused on two SVI themes that were most closely aligned with the school-level data: 1. SES (incorporates residents below the poverty level, unemployment, income, and no high school diploma) and 2. race/ethnicity (minoritized residents and those who speak English “less than well”). Higher SVI scores indicate increased vulnerability relative to other census tracts with lower scores at the time that the index was evaluated.

We defined adjacent neighborhoods using the school attendance zones so that we could test whether relationships between GI abundance and demographics in schoolyards were
different than in the surrounding urban landscape. Each school attendance zones represented the geographic extent served by a local school for the purpose of student assignment (USDE, 2016). The GIS (Geographic Information System) data of school attendance zone was collected by the School Attendance Boundary Survey which was conducted by the National Center for Education Statistics (NCES) for 2015-2016 school year (USDE, 2016). As school attendance zones may change every year, we verified the boundaries with the latest elementary school information of each county (Figure 2.1) (Cumberland County Open Data, 2018; Mecklenburg County GIS, 2019; Wake County Public School System, 2019). Each school attendance zone defined neighborhood covered one to several census tracts, and the average size of the neighborhoods was 1.6 to 2.5 times larger than the size of the census tract unit (Table S1). Specifically, the average extent of a neighborhood (SD) was 10.26 km² (± 8.03 km²) in Fayetteville, 17.06 km² (± 9.82 km²) in Winston-Salem, 9.95 km² (± 7.24 km²) in Charlotte and 10.26 km² (± 6.52 km²) in Raleigh. Since neighborhoods crossed multiple census tract units, the census tract level SVI data was up-scaled to fit the neighborhood boundary. We used an area weighted averaging approach based on (Saia et al., 2019) in ArcGIS 10.4 (Environmental Systems Research Institute, 2016) to assign SVI scores to neighborhoods that crossed multiple census tracts. Although we use school attendance zones to represent neighborhoods adjacent to schools, it is important to note that the student populations in some of the study cities (Raleigh, Charlotte, Winston-Salem) are drawn from outside the school attendance zones through magnet programs designed to increase school diversity (Riel, Parcel, Mickelson, & Smith, 2018).

2.2.3 Land cover classification

We used 2016 color infrared (CIR) imagery (1 m resolution, resampled to 5 m for
computational capacity) from National Agriculture Imagery Program (NAIP) to classify land
cover for all school districts (USDA, 2016), except Charlotte, for which 2014 imagery was the
most recent data available (USDA, 2014). Imagery was allocated to land cover classes using
Random Forest, a supervised classification method (Breiman, 2001) that has been applied in
previous urban land cover classification studies (Hayes, Miller, & Murphy, 2014).

Our land cover classification scheme was based on HERCULES, a widely used
classification framework for urban landscapes (Cadenasso et al., 2007). We began with an initial
six land cover types: (1) bare ground, (2) roads/parking lots, (3) buildings, (4) fine vegetation
(grass/lawn and other herbaceous vegetation), (5) coarse vegetation (trees and shrubs) and (6)
water. Vegetation was further refined to calculate tree canopy cover, as explained below. We
randomly generated 75 to 130 sample polygons for each type of land cover within each school
district boundary (Congalton, 1991) to extract the pixel value from NAIP imagery as supervised
training datasets. Three researchers labeled samples with 100% agreement in labeling, owing to
the simple and unambiguous schema. We split all datasets into 70% training and 30% testing.
Random Forest analyses were conducted in R 3.4.2 (R Core Team, 2014).

We used post-processing procedures to improve classification accuracy including editing
features based on ancillary official building footprints vector data (NC One Map, 2021). We
generated stratified random points within neighborhoods for the accuracy assessment, and
sampled a total of 250 points in each study location, with 50 random points for each class. We
validated the classified categories with the latest high-resolution orthoimagery (0.3 meter) by
pixel-by-pixel comparison (Zhou, 2013). As the NAIP imagery dates differed among counties,
we conducted the training and accuracy assessments separately for each county. As we were
interested in tree canopy cover, we used the North Carolina Forest (Tree) Land Cover data,
which contained 2-class classification schema forest/trees and non-forest/trees (NC One Map, 2019a), to assist separating trees and shrubs. Then we merged trees, shrubs, grass/lawn and other herbaceous vegetation into a total GI category for further analysis. We compared the tree canopy cover and total GI within neighborhoods and school parcels within urban boundaries. The geospatial location for elementary schools and the school boundaries were created from NC One Map, (2019b) by merging parcels belonging to the board of education.

2.2.4 Statistical analyses

*Bivariate analyses*

We analyzed the bivariate relationship between GI and demographics for each city and four cities as a whole using Spearman’s correlation, which allowed us to investigate any disparities in GI distribution and each demographic characteristic (Kuo, Browning, Sachdeva, et al., 2018; Schwarz et al., 2015). At the schoolyard level, we analyzed bivariate relationships between tree canopy cover and demographic variables (FRL and Peoples of Color), as well as the bivariate relationships between total GI and the same two demographic variables. Similarly, at the neighborhood level, we examined the bivariate relationships between tree canopy cover and total GI and the two SVI themes (SES and race/ethnicity).

*Multivariate analyses*

We used multivariate regression to analyze the relationship between spatial distribution of GI and demographic variables, a technique which has been widely applied to address concerns about GI distribution across population demographics (Gerrish & Watkins, 2018; Pham et al., 2012; Schwarz et al., 2015). The multivariate regression model quantified the relationship between the GI and multiple independent variables, expanding the understanding gained from
the initial bivariate analysis (Schwarz et al., 2015). As multivariate regression models capture the
effect of covariates, results are sometimes different from bivariate analyses (Schwarz et al.,
2015). We used ordinary least squares regression (OLS) (Baltagi, 2007) to examine relationships
between tree canopy cover and total GI (as responses variables) and FRL rate and the
percentage of students identifying as Peoples of Color Peoples of Color (independent variables)
in schools, and two SVI themes (independent variables) in the neighborhoods. OLS rests on the
assumption that independent variables are identically distributed and the error terms have no
autocorrelation (Schwarz et al., 2015). However, spatial data tends to exhibit spatial
autocorrelation (e.g. trees tend to be close to each other) (Schwarz et al., 2015; Tobler, 1970). As
OLS may not be able to capture the spatial autocorrelation, we used Moran’s I (Moran, 1950) to
test the spatial autocorrelation among residuals for all OLS. When Moran’s I identified spatial
autocorrelation, we applied a spatial regression model to address the spatial variations. The
model was based on previous research from Schwarz et al., (2015) which applied a spatial lag
model (SLAG) to analyze relationships between tree canopy cover and median household
income in urban areas.

In our study, we assumed that tree canopy cover and total GI were directly influenced by
the extent of neighboring tree canopy cover and total GI. SLAG introduced spatially lagged
dependent variables for a matrix of weights (Baltagi, 2007), taking the form of

$$ y = \rho Wy + X \beta + \epsilon $$

where $Wy$ is the spatially lagged the tree canopy cover /total GI. $W$ is the matrix of spatial
weights representing possible locational associations among sample points (i.e. invert distance
between data points or 8-nearest-neighbor depending on which weight matrix gave the best
model). $\rho$ reflects the strength of spatial dependencies between the elements of the dependent
variable; $\beta$ is coefficient; $X$ is independent variables including Peoples of Color and FRL for schools and two SVI themes for neighborhoods; $\varepsilon$ is a vector of error terms (Baltagi, 2007).

*Moran’s I* was tested again to ensure no spatial autocorrelation after using SLAG. We used Akaike Information Criterion (AIC), a method that accounts descriptive accuracy and parsimony, to compare model performance between OLS and SLAG and select the best model with the lowest AIC value (Wagenmakers & Farrell, 2004; Yamaoka, Nakagawa, & Uno, 1978). All analyses were conducted for each city and four cities as whole in R 3.4.3 (R Core Team, 2014).

### 2.3 Results

#### 2.3.1 Demographics in schools and adjacent neighborhoods

Our analyses of school demographics indicated that all schools were majority Peoples of Color ($\pm$ SD), comprising between $56.3 \pm 20.4\%$ of students in Raleigh and exceeding $76\%$ of students in Charlotte ($\pm 25.9\%$) and Fayetteville ($\pm 14.4\%$). Likewise, neighborhoods across all four cities had race/ethnicity SVI scores higher than the US average (Table 2.1). Overall, Fayetteville had the highest SVI scores, and scored highest at both the schoolyard level FRL ($\pm$ SD) rates at $85.5 \pm 22.1\%$, and SVI SES. Charlotte was the most diverse city, with the largest standard deviation in the school FRL rate ($69.3 \pm 37.9\%$), and neighborhood SES SVI, and scoring highest for race/ethnicity SVI. Raleigh has the lowest SVI score, with the lowest rates of FRL ($37.8 \pm 20.4\%$) and a SES SVI score lower than the US average.
Table 2.1. The average of demographics statistics (SD) at the school and neighborhood (school attendance zones) scales across the urban portion of school districts and the rate of tree canopy cover and total green infrastructure, GI (SD).

<table>
<thead>
<tr>
<th></th>
<th>FRL a</th>
<th>People of Color b</th>
<th>SVI SES c</th>
<th>SVI race/ethnicity d</th>
<th>Tree canopy cover Schools</th>
<th>Tree canopy cover Neighborhoods</th>
<th>Total GI schools</th>
<th>Total GI neighborhoods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayetteville</td>
<td>85.5%</td>
<td>76.6%</td>
<td>2.26</td>
<td>1.30</td>
<td>18.8%</td>
<td>48.9%</td>
<td>60.6%</td>
<td>75.0%</td>
</tr>
<tr>
<td></td>
<td>(22.1%)</td>
<td>(14.4%)</td>
<td>(0.58)</td>
<td>(0.14)</td>
<td>(14.5%)</td>
<td>(7.3%)</td>
<td>(15.9%)</td>
<td>(7.7%)</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>74.0%</td>
<td>68.4%</td>
<td>2.05</td>
<td>1.20</td>
<td>27.9%</td>
<td>49.5%</td>
<td>61.9%</td>
<td>73.6%</td>
</tr>
<tr>
<td></td>
<td>(33.4%)</td>
<td>(28.6%)</td>
<td>(1.04)</td>
<td>(0.46)</td>
<td>(15.3%)</td>
<td>(9.4%)</td>
<td>(11.4%)</td>
<td>(12.1%)</td>
</tr>
<tr>
<td>Charlotte</td>
<td>69.3%</td>
<td>76.4%</td>
<td>1.79</td>
<td>1.34</td>
<td>30.6%</td>
<td>47.6%</td>
<td>65.0%</td>
<td>71.3%</td>
</tr>
<tr>
<td></td>
<td>(37.9%)</td>
<td>(25.9%)</td>
<td>(1.09)</td>
<td>(0.44)</td>
<td>(15.3%)</td>
<td>(9.2%)</td>
<td>(12.4%)</td>
<td>(9.2%)</td>
</tr>
<tr>
<td>Raleigh</td>
<td>37.8%</td>
<td>56.3%</td>
<td>1.17</td>
<td>1.10</td>
<td>35.0%</td>
<td>51.8%</td>
<td>65.1%</td>
<td>74.0%</td>
</tr>
<tr>
<td></td>
<td>(20.4%)</td>
<td>(20.4%)</td>
<td>(0.72)</td>
<td>(0.37)</td>
<td>(14.5%)</td>
<td>(9.5%)</td>
<td>(11.0%)</td>
<td>(7.5%)</td>
</tr>
<tr>
<td>Continental US</td>
<td>-</td>
<td>-</td>
<td>1.99</td>
<td>0.98</td>
<td>29.9%</td>
<td>49.6%</td>
<td>63.8%</td>
<td>73.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.98)</td>
<td>(0.54)</td>
<td>(15.8%)</td>
<td>(9.2%)</td>
<td>(12.3%)</td>
<td>(8.9%)</td>
</tr>
</tbody>
</table>

a Free and Reduced Lunch, FRL, is the average free and reduced lunch population of schools, presenting the SES of students who attend schools (U.S. Department of Education, 2019).

b People of Color, Peoples of color represents the combined population of students of race/ethnicities other than “White”, representing the race/ethnicity of schools (U.S. Department of Education, 2019)

c SVI SES theme presents the Social Vulnerability Index (SVI) socioeconomic status (SES) of neighborhoods (school attendance zones).

d SVI race/ethnicity theme presents the Social Vulnerability Index (SVI) race/ethnicity status of neighborhoods.

2.3.2 Land cover in schools and adjacent neighborhoods

Our land cover classification had the user’s accuracy of coarse vegetation exceeding 90% for all school districts and the user’s accuracy of fine vegetation exceeding 85% in most study sites, indicating that the classified vegetation result was reliable (Hayes et al., 2014; Story & Congalton, 1986). Details of the accuracy results are reported in the supplementary (Table S2), including the overall, user’s and producer’s accuracies. The overall accuracy was 82.4% (Kappa = 0.78) in Fayetteville, 80.4% (Kappa = 0.76) in Winston-Salem, 85.2% (Kappa = 0.81) in
Charlotte, and 86.4% (Kappa = 0.83) in Raleigh (for the error matrix table, see Table S3). Zoomed in maps of the schoolyard and neighborhood land covers for each school districts are shown in Figure 2.2.

![Map of Schoolyards and Neighborhoods](image)

**Figure 2.2.** Zoomed in examples of schools’ and neighborhoods’ (school attendance zones) land cover in the four school districts.

Across all cities, the average tree canopy cover in schoolyards was lower than in the neighborhoods (Table 2.1). In schoolyards, tree canopy cover (± SD) ranged between 19 ± 14% in Fayetteville and 35 ± 14% Raleigh. In neighborhoods, all cities had approximately 50% tree canopy cover (Table 2.1).

In the majority of schoolyards, mean total GI exceeded 60% in all school districts, ranging between 61± 15.9% in Fayetteville to 65 ± 11% in Raleigh (Figure 2.3). In neighborhoods, total GI of the four cities was higher than in schoolyards, all above 70%. Within total GI, grass/lawn (fine vegetation) was a considerable land cover type and generally more
extensive in schoolyards than in neighborhoods (Table S4). Across the four cities, grass/lawn occupied nearly a third of the school properties on average (34 ± 12%), which is about 10% greater than the average grass/lawn cover in neighborhoods (24 ± 5%).

**Figure 2.3.** Spatial distribution of tree canopy (tree canopy cover), total GI (total green infrastructure) and SVI for socioeconomic (SES) and race/ethnicity in neighborhoods (school attendance zones).
2.3.3 Statistical results

*Bivariate correlation results*

At the schoolyard scale, we found very few relationships between land cover and school demographics in any of the cities (Table 2.2). The only statistical relationship was a positive relationship between tree canopy cover and FRL (p < 0.05) in Raleigh. The remaining correlations between tree canopy cover or total GI and FRL were not statistically significant. Likewise, we did not find any statistically significant correlations between tree canopy cover or total GI and the race/ethnicity in schools in any of the cities or when the cities were combined.

Table 2.2. Spearman’s correlation results of tree canopy cover (tree canopy cover), total GI (total green infrastructure) and 1. school-level measures of socioeconomic status (free and reduced lunch population; FRL) and People of Color (students identifying as people of color) as well as 2. neighborhood measures of socioeconomic status (SVI SES) and people of color (SVI race/ethnicity).

<table>
<thead>
<tr>
<th></th>
<th>FRL</th>
<th>People of Color</th>
<th>SVI SES</th>
<th>SVI race/ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tree canopy</td>
<td>total GI</td>
<td>tree canopy</td>
<td>total GI</td>
</tr>
<tr>
<td>cover</td>
<td>cover</td>
<td></td>
<td>cover</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fayetteville</td>
<td>0.25</td>
<td>0.06</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>-0.05</td>
<td>-0.24</td>
<td>-0.05</td>
<td>-0.24</td>
</tr>
<tr>
<td>Charlotte</td>
<td>0.06</td>
<td>-0.04</td>
<td>0.01</td>
<td>-0.02</td>
</tr>
<tr>
<td>Raleigh</td>
<td>0.25 *</td>
<td>0.10</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>Average</td>
<td>-0.08</td>
<td>-0.07</td>
<td>-0.04</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Note: ' p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

In our analysis of neighborhoods, there were some significant correlations between increased vulnerability and lower GI (Table 2.2, Figure 2.3). When examining the four cities
together, there was less tree canopy cover and total GI in neighborhoods with higher SES SVI scores \( (p < 0.001) \). When examining the four cities individually, we found significant negative correlations between SES vulnerability and both tree canopy cover and total GI in Winston-Salem \( (p < 0.01) \) and in Charlotte \( (p < 0.01) \). In Raleigh, we identified a negative relationship between SES and tree canopy cover \( (p < 0.05) \), but no significant relationship with total GI. There was no relationship between tree canopy cover and SES vulnerability in Fayetteville. For race/ethnicity, the four cities on average, there was also less total GI and tree canopy cover in neighborhoods with higher race/ethnicity scores \( (p < 0.001) \). We found significant negative relationships between race/ethnicity and tree canopy cover in Winston-Salem and Raleigh \( (p < 0.01) \). We also found significant negative relationships between race/ethnicity and total GI in Winston-Salem \( (p < 0.01) \) and Charlotte \( (p < 0.05) \), and weaker negative relationships in Raleigh and Fayetteville \( (p < 0.1) \).

*Multivariate models*

a. *Schoolyards*

Across schoolyards, the relationships between tree canopy cover, FRL and Peoples of Color were consistent (Table 2.3). We did not find any significant relationships between tree canopy cover, FRL and Peoples of Color using OLS in any individual city or the four cities combined. Similarly, we did not find any significant relationships between total GI, FRL and Peoples of Color in any city or when the cities were combined. Across the four cities, we adopted a SLAG only for cities whose OLS showed spatial autocorrelation from Moran’s test. When applying SLAG, we found that SLAG improved AIC scores in Raleigh and the four cities as a whole when modeling both tree canopy cover and total GI with school demographics.
Table 2.3. OLS and SLAG for tree canopy cover, total green infrastructure, GI, and demographics in schools including socioeconomic status (free and reduced lunch population; FRL) and People of Color (students identifying as people of color).

<table>
<thead>
<tr>
<th></th>
<th>Fayetteville</th>
<th>Winston-Salem</th>
<th>Charlotte</th>
<th>Raleigh</th>
<th>All four cities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OLS</td>
<td>SLAG</td>
<td>OLS</td>
<td>SLAG</td>
<td>OLS</td>
</tr>
<tr>
<td>tree canopy cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRL</td>
<td>0.13</td>
<td>-</td>
<td>-0.19</td>
<td>-</td>
<td>0.10</td>
</tr>
<tr>
<td>People of Color</td>
<td>-0.008</td>
<td>-</td>
<td>0.19</td>
<td>-</td>
<td>-0.12</td>
</tr>
<tr>
<td>AIC</td>
<td>-37.4</td>
<td>-27.1</td>
<td>-77.8</td>
<td>-</td>
<td>-95.5</td>
</tr>
<tr>
<td>total GI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRL</td>
<td>0.002</td>
<td>-0.02</td>
<td>-0.16</td>
<td>-</td>
<td>0.07</td>
</tr>
<tr>
<td>People of Color</td>
<td>-0.01</td>
<td>-0.06</td>
<td>0.07</td>
<td>-</td>
<td>-0.1</td>
</tr>
<tr>
<td>AIC</td>
<td>-28.5</td>
<td>-44.0</td>
<td>-51.2</td>
<td>-</td>
<td>-113.3</td>
</tr>
</tbody>
</table>

Note: * p < 0.1, ** p < 0.05, *** p < 0.001
“-”: no spatial autocorrelation was identified

b. Neighborhoods

The relationships between tree canopy cover and total GI and neighborhood SES and race/ethnicity status varied across the study cities (Table 2.4). In Winston-Salem and Fayetteville, we did not find significant relationships between tree canopy cover or total GI and either of the SVI themes using OLS or SLAG. In Charlotte, we found a strong negative relationship between SES and both tree canopy cover and total GI (p < 0.01) using OLS. The negative association was weaker between SES and both tree canopy cover (p < 0.1) and total GI (p < 0.05) using SLAG. In Charlotte, SVI for race/ethnicity was negatively associated with total GI using OLS (p < 0.05) but was not significant using SLAG. In Raleigh, race/ethnicity was negatively associated to tree...
canopy cover and total GI (p < 0.05) using both OLS and SLAG. In the four cities as a whole, SES was negatively associated with tree canopy cover (p < 0.01) and total GI (p < 0.05) using OLS but not SLAG; race/ethnicity had a negative association with total GI (p < 0.05) and had a weaker association with tree canopy cover (p < 0.1) using SLAG.

Table 2.4. OLS and SLAG models for tree canopy cover, total green infrastructure, GI, and demographics in neighborhoods, including measures of socioeconomic status (SVI SES) and peoples of color (SVI race/ethnicity).

<table>
<thead>
<tr>
<th></th>
<th>Fayetteville OLS</th>
<th>Fayetteville SLAG</th>
<th>Winston-Salem OLS</th>
<th>Winston-Salem SLAG</th>
<th>Charlotte OLS</th>
<th>Charlotte SLAG</th>
<th>Raleigh OLS</th>
<th>Raleigh SLAG</th>
<th>All four cities OLS</th>
<th>All four cities SLAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>tree canopy cover SVI SES (SVI race/ethnicity)</td>
<td>-0.007 0.04 **</td>
<td>-0.03 0.02 '</td>
<td>-0.03 0.01 **</td>
<td>-0.04 0.03 **</td>
<td>-0.04 0.004 0.004</td>
<td>-0.02 0.01</td>
<td>-0.02 0.004 0.004</td>
<td>-0.04 0.004 0.004</td>
<td>-0.02 0.01</td>
<td></td>
</tr>
<tr>
<td>AIC</td>
<td>-94.1 71.6 5</td>
<td>-73.6 177.5 5</td>
<td>-194.4 223.9 5</td>
<td>-249.8 -533.8 5</td>
<td>-226.1 -239.2 5</td>
<td>-619.4 -541.7 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total GI SVI SES (SVI race/ethnicity)</td>
<td>-0.004 0.01 0.05</td>
<td>-0.01 0.01 0.01</td>
<td>-0.05 0.01 0.06</td>
<td>0.01 0.05 0.06</td>
<td>-0.02 0.003 0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIC</td>
<td>-89.7 52.3 3</td>
<td>-66.4 187.3 3</td>
<td>-202.6 -226.1 3</td>
<td>-239.2 -619.4 3</td>
<td>-541.7 -619.4 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ' p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001
“-”: no spatial autocorrelation was identified

2.4 Discussion

Encouragingly, GI distribution across schoolyards was unrelated to student demographics, supporting arguments that greening schoolyards may help mitigate the disparities in the distribution of GI and its benefits. The lack of relationship between GI and school demographics is promising, especially as the urban schools we examined were from the largest
school districts in the state of North Carolina and had majorities of students identifying as Peoples of Color. As articulated in the green schoolyards research agenda presented by Stevenson et al. (2020), providing greener school grounds is a way to ensure all students have access to GI, nature, and the resulting benefits during the significant portion of their time at school, even when they may not have the same level of abundance or access at home.

While school GI was not related to demographics, this was not true in the neighborhoods, (defined by school attendance zones). Our results are largely consistent with previous literature documenting the unequal distribution of GI, where communities of color and areas of lower SES are less green. For instance, Schwarz et al., (2015) found that tree canopy cover across several major cities tended to be lower in census tracts with higher percentages of peoples of color (e.g. Black and Hispanic) and low income neighborhoods. The environmental injustices of GI distribution across neighborhoods can be explained by the systemic and historic discrimination and racism such as racially discriminatory land use regulation and housing policies at local and state levels that shape residential geographies in the US (Rigolon & Németh, 2018). Accordingly, we reiterate the need to characterize, as well as generate solutions to the potential environmental injustices associated with the unequal distribution of GI across landscapes and communities. These solutions will require meaningful involvement of the communities to meet the US Environmental Protection Agency’s definition of Environmental Justice.

The more even distribution of GI in schoolyards suggests that schools may provide a mechanism for more equal distribution of GI across municipalities, but there are several caveats to consider related to access and use. In addition to the presence and abundance of GI, access to that space is an important consideration. Access to green space can refer to how easily people can use nearby green space (e.g. parks), usually assessed by the walk distance or other travel cost
Studies that examine access to green space often find similar racial and ethnic disparities (Dai, 2011; Nesbitt, Meitner, Girling, Sheppard, & Lu, 2019; Rigolon, 2016) to studies such as ours that examine the distribution of tree canopy cover and total GI. School attendance zones may not capture the full range of green space a neighborhood can access, and schoolyards may not be accessible to the broader communities. Some of the benefits of GI on schoolyards may have the potential to translate to the broader community regardless of access, such as mitigating stormwater (Stevenson et al., 2020). But others, such as providing green space in places where public parks and city gardens are deficient, and increasing green space connectivity (Iojă et al., 2014), depend on providing access to schoolyards to the public. In many cases, school grounds are locked and inaccessible to communities after-hour weekday evenings and weekends due to liability or legal concerns, or maintenance costs (Ogilvie & Zimmerman, 2010; Turner, Calvert, & Chaloupka, 2018).

Although GI is distributed more equitably in schoolyards, we found lower levels of GI, particularly tree canopy cover, as compared to neighborhoods. This represents an opportunity to extend the potential of schools to help address environmental injustices related to access to GI and its benefits. As we discussed above, metrics from the City of Raleigh indicate impervious surface cover can be extensive at schools (UNC EFC, 2018). This suggests that school systems are an important priority partner to expand urban green space and to focus efforts on improving GI quality as well as quantity. Evidence suggests students prefer green cover than gray surfaces (Lindemann-Matthies & Kölhler, 2019), and receive multiple ecosystem benefits from green schoolyards with expansive GI, such as educational services, improved social-emotional well-being and overall green space connectivity (Iojă et al., 2014; van Dijk-Wesselius et al., 2018). In particular, we suggest that efforts to expand GI on schools move beyond current design regimes.
dominated by grass/lawn (Andersen, Klinker, Toftager, Pawlowski, & Schipperijn, 2015) to focus on trees. Despite documented concerns over perceived safety or cost to plant and maintain trees (Iojă et al., 2014; van Dijk-Wesselius, van den Berg, Maas, & Hovinga, 2020), trees provide a myriad of benefits to people and landscapes. Many of these we highlighted earlier, including those related to academic performance (Kuo, Browning, Sachdeva, et al., 2018; Sivarajah et al., 2018) mental health (Chawla et al., 2014), physical health, and regulation services (Keeler et al., 2019). Specific to the school context, trees have also been linked to building connection between children and nature (Laaksoharju & Rappe, 2017), providing natural settings for recreation (Andersen et al., 2015) and outdoor education (Kerlin et al., 2015). Expanding multifunctional GI including trees and other green stormwater infrastructure in schoolyards would provide these benefits to populations that arguably benefit from them most (i.e., children), and in an equitable way, as schools are found in every community, regardless of social vulnerability. When schoolyards can be safely accessed and used by broader communities, such as opening schoolyards after school and during in summer/winter break, GI in schoolyards may help address community challenges; for example, gardens in schoolyards can be part of urban agriculture systems that can strengthen community food security (Keeler et al., 2019).

Currently, the facilitation of multi-functional GI is may not be well integrated in school systems. For example, the Wake County, North Carolina school district, which includes the city of Raleigh, provides the basic standards for outdoor facilities, requiring one sports field covered by grass (similar size as soccer fields), two playfields covered by impervious surface (one for k-2 and one for 3-5 grade). But, there is no specific guideline for GI in schoolyards (e.g., how many trees, the size of green spaces) according to North Carolina Public School districts as well as individual school district (Charlotte-Mecklenburg Schools, 2019; North Carolina State Board of
These requirements could be shaped to expand GI across school districts and maintain the equity we identified in GI quantity we identified in this study.

2.5 Limitation and Future Research

It is not clear how common our findings of equal, but lower tree canopy cover and total GI in schoolyards compared to surrounding neighborhoods, might be. Our study sites were all in North Carolina, where tree canopy cover is generally high compared to national averages (USFS, 2019). In addition, our findings may not be applicable in other countries where school policies, education systems, racial/ethnic history and SES contexts are different.

Since SVI is a consolidated category of race and ethnicity, our results may not be able to provide further information regarding to the nuanced relationship between GI and specific racial or ethnic groups. The relationship between GI and different identity groups may vary; some may be more vulnerable than others, depending on factors including the history and nature of structural marginalization each individual group has endured (Nesbitt et al., 2019; Rigolon, 2016; Schwarz et al., 2015).

2.6 Conclusion

Our study focuses on the distribution of GI, particularly tree canopy cover and total GI across school districts to explore whether public schoolyards provide more equal distribution of green space than the surrounding urban landscape. We addressed this by (1) categorizing the land cover in public elementary schoolyards as well as in the surrounding neighborhoods using a random forest approach to classify high resolution remotely sensed data and (2) by analyzing the relationship between tree canopy and total GI with demographics. Our findings support the
conclusion that public elementary schoolyards provide equal exposure to GI, which is not the case in surrounding neighborhoods. Schoolyards were majority green (> 60%), however, they were less green when compared to neighborhoods and varied by school district. Therefore, public school systems are a promising partner to expand GI and urban greening equitably. When expanding school greenness, we recommend that future landscape practitioners focus on increasing the trees as well as implementing multi-functional GI.
Acknowledgements

This research was supported by a graduate student grant through the North Carolina Water Resources Research Institute (WRRI) and North Carolina Sea Grant (NCSG) Joint Graduate Student Research Funding Opportunity.
CHAPTER 3. EXPLORING GEOGRAPHICAL, CURRICULAR, AND DEMOGRAPHIC FACTORS OF NATURE USE BY CHILDREN IN URBAN SCHOOLYARDS IN RALEIGH, NC, USA

Zhenzhen Zhang, Kathryn T. Stevenson, Katherine L. Martin


Abstract

Experience in nature provides a host of benefits to children, but today’s children who live in urban environments spend less time with nature compared to previous generations. Because children spend a large amount of time at school, greening schoolyards is one strategy for providing children with more access to nature and its benefits. However, installing nature-rich spaces in schoolyards may not guarantee their use, and research is needed to understand how the physical make-up of schoolyards may interact with teacher and student-related factors to predict use of natural elements on schoolyards. We inventoried 9 urban schoolyards and surveyed an associated 199 3rd-6th grade students and 14 teachers to measure children’s awareness and use of nature-rich vs. traditional outdoor spaces as predicted by teachers’ behavior (i.e. taking students outdoors) and environmental education-related training, student demography, and schoolyard physical environment. We found that children were less aware of nature-rich spaces (gardens 69%, woodlands 28%) compared to traditional outdoor spaces (playgrounds 73%, athletic fields 77%) and spent less time there (once a month versus several times a week). However, teachers taking children outdoors (p = 0.001) and trained in environmental education (p = 0.10) positively predicted student awareness and use of nature-rich spaces gardens. Teacher training in environmental education was also predictive of children exploring woodlands (p =
0.04), highlighting the importance of teacher training in successful green schoolyard efforts. We provide a glimpse of schoolyards as places for urban children to access nature benefits by studying different school factors that influence children’s nature-based activities. Simply implementing natural spaces in schoolyards cannot guarantee the use of natural spaces by children. Providing institutional support and professional development for teachers may help to enhance children awareness of different nature-rich areas and promote nature-base activities in schoolyards.

3.1 Introduction

The world population has exhibited an urbanizing trend over the past decades, with growing numbers of people moving to urban areas (Bratman et al., 2019). Urbanization can limit people’s contact with nature; however, because nature provides a host of benefits to human health and well-being, urban planners and policy makers are challenged to provide urban residents access to nature and the host of benefits that it can provide (Akoumianaki-Ioannidou et al., 2016; Bratman et al., 2019). For example, time spent walking or viewing nature provides significant benefits to both physical and mental health for urban residents (Bratman et al. 2019; Lee et al. 2011). Further, contact with nature provides social and cultural benefits (Jennings & Bamkole, 2019). For example, urban green spaces such as parks provide places for interaction between people from various social and ethnic backgrounds and can promote a sense of place and belonging (Jennings & Bamkole, 2019). Much of this research highlights the benefits of time in nearby natural areas like private gardens or municipal parks (Detweiler et al., 2015; Song, Ikei, Igarashi, Takagaki, & Miyazaki, 2015), which is encouraging as these areas may be accessible to an increasingly urbanizing population (James et al., 2009).
Access to nature may provide particularly strong benefits to children, laying the foundation for healthy adulthoods. For instance, natural settings promote children’s physical development by supporting more diverse, imaginative and creative play than settings with fewer natural elements (Herrington & Brussoni, 2015; Kuo, Barnes, & Jordan, 2019; Moore, 1986). The physical activity encouraged by outdoor play is positively related to benefits including improving metabolism, cardiorespiratory fitness and skeletal health (Ortega et al., 2008). Natural settings like trees and shrubs offer places for constructive and social play which foster children’s motor development and social interaction (Fjørtoft, 2001; Fjørtoft, 2004). Nature can also help restore children’s attentional function. For instance, children who have attention deficit disorder function better after playing in green settings (Taylor and Kuo 2009). A large body of research supports the notion that laying the foundation for mental, physical, and social health in childhood is linked to healthier adulthoods (Edwards, Holden, Felitti, & Anda, 2003; Telama et al., 2014). Further, research suggests that childhoods spent in nature may promote nature-based recreation (Asah, Bengston, & Westphal, 2012) as well as pro-environmental attitudes and environmental stewardship (Cheng & Monroe, 2012; Wells & Lekies, 2006) in adulthood. Accordingly, time in nature may ensure that individuals are continually motivated to both access the benefits provided by nature as well as take steps to protect nature itself.

Despite the myriad of benefits provided by time in nature, today’s children, certainly including those who live in urban environments, spend less time in nature than did previous generations (Larson et al., 2011; Natural England, 2009). Children’s level of screen time is often cited as a major cause of this apparent generational decline of time in nature (Bonnell, Hargiss, & Norland, 2019; Larson et al., 2011). Over half of US children in grades 6 to 12 spent over two hours in screen-based activities such as watching TV or playing video games (Leatherdale &
Ahmed, 2011). Similarly, over 40% children in age 8-12 and 84% children in age 13-18 have personal smartphones (Rideout & Robb, 2019). Other factors like discomfort with snakes, insects, poisonous plants and fear of getting lost may further reduce the chance of children interacting with nature (Bixler, Carlisle, Hammitt, & Floyd, 1994; Bonnell et al., 2019). Some have found that children are more interested in spending time outdoors playing sports, jogging and biking, which may not provide all the benefits highlighted above because they are not specifically focused on nature (Larson et al., 2011).

In addition to the decline in average time children spend in nature, not all children have equitable access to nature (Stevenson et al., 2020). Low-income neighborhoods and racial and ethnic minority communities often have less access to safe and high quality urban green spaces than their higher income or white counterparts (e.g. Astell-Burt et al., 2014; Rigolon, 2016). The many benefits that nature provides seem to address some of the same health disparities experienced by these same communities such as depression, stress, and cardiovascular disease (Mitchell et al., 2015). Research has revealed health inequities to be associated with low-income and minority communities (Mitchell and Popham 2008). For example, blood pressure risks, metabolic risk and inflammation risk are found to be higher in African Americans (Williams & Mohammed, 2009); mental health risks were higher in children and adolescents with low socioeconomic status (Reiss, 2013). Children from low-income communities with less access to nature have higher risks for behaviour problems, whereas increasing the access to nature may buffer children from health inequities by promoting positive development outcomes (Bates et al., 2018). Accordingly, in some cases, the children who may benefit most from nature are the very ones with the least amount of access and exposure to it (Stevenson et al., 2020).

One possibility for providing access to nature and its benefits in urban settings is focusing
on greening schoolyards (Stevenson et al., 2020), as children spend a significant proportion of their daily lives in schools (Akoumianaki-Ioannidou et al., 2016; Jansson, Gunnarsson, Mårtensson, & Andersson, 2014). Traditional school grounds are flat, barren areas usually covered by impervious surfaces such as asphalt, or open spaces with turf and a few trees surrounded (Dyment & Bell, 2008; Fjørtoft, 2004; Lindemann-Matthies & Köhler, 2019). In recent decades, there are a growing number of schoolyard greening initiatives across the US and the world such as San Francisco Unified School District Green Schoolyard Program (San Francisco Public Schools, 2017), Space to Grow in Chicago (Children & Nature Network, 2016), or the Schoolyard Habitat Program across the United States (U.S. Fish and Wildlife Service, 2018). Green schoolyards can vary in specific make-up, but they all have multi-functional and nature-filled green spaces such as gardens, nature play areas, trails, or outdoor classroom (Bikomeye, Balza, & Beyer, 2021; Children & Nature Network, 2016). They are designed to support students and teachers to play, learn, and explore during school, as well as to provide communities with access to nature and its benefits (Stevenson et al., 2020). For example, children attending schools with green schoolyards had higher scores in psychological well-being compared to children from schools without greening improvement (Kelz, Evans, & Röderer, 2015); researchers also observed increased physical activity after greening schoolyards, especially among girls (Raney, Hendry, & Yee, 2019). In addition to all the mental, physical, and social benefits (Bikomeye, Balza, et al., 2021), a growing body of research suggests that green schoolyards may support academics. For instance, school greenness is positively associated with math and English achievement (Kuo, Browning, Sachdeva, et al., 2018; Leung et al., 2019), and many education scholars highlight how natural settings are ideal settings for theory-driven approaches such as inquiry-based learning (Acharya, 2018), interdisciplinary instruction
(Guerrero & Reiss, 2020), and place-based learning (Chawla & Derr, 2012). Finally, because of the compulsory nature of schooling in the United States and many areas of the world (UNESCO, 2015), greening schoolyards is one promising strategy for ensuring all children have access to nature and its benefits.

Though promoting the instillation of green schoolyards can support children’s well-being, accessing their benefits depends on use by students and teachers. Even when natural elements are available on schoolyards, research has found numerous barriers to use of green schoolyards. For instance, students who had negative attitude towards nature (e.g. fear of wildlife) were less willing to play in nature (Beyer et al., 2015; Bixler et al., 1994). Teachers can facilitate children’s access nature by taking children outdoor and using natural elements for educational purposes and recess (Bates et al., 2018; van Dijk-Wesselius et al., 2020), however many barriers can impede teachers’ use schoolyards. Teachers often cite lack of time to be the reason for not incorporating outdoor activities into the school day (Dyment, 2005; Ernst, 2014; van Dijk-Wesselius et al., 2020), which may point to prescriptive curricula that leave little room for deviation from traditional classroom settings (van Dijk-Wesselius et al., 2020). Teachers also identified students’ safety and comfort as other concerns for teaching outdoors (Marchant et al., 2019). Lack of training is another barrier: teachers cite lack of confidence, knowledge, and skills for facilitating outdoor learning (Ernst, 2014), highlighting the need for professional development specific to teaching in outdoor settings (Ernst, 2012). In addition, a persistent emphasis on high stakes testing may dissuade teachers from engaging in outdoor instruction (Marchant et al., 2019) or administrators from allowing it (Dyment, 2005; Ernst, 2012), driven by a perception that there is no time to go outdoors and attend to tested standards simultaneously (Marchant et al., 2019). Together, this research presents a fairly complex picture for
understanding how to ensure green schoolyards are both implemented and used. Many studies focus on a single sets of factors, such as inventorying school attributes (Dyment et al., 2009; Samborski, 2010), linking attributes to student behaviour (Cosco, Moore, & Islam, 2010; Dyment & Bell, 2008; Lucas & Dyment, 2010), or focusing on educator motivations for taking students outdoors (Beyer et al., 2015; Stevenson et al., 2013). However, the relative importance of these factors to promote implementation and use of green schoolyards is understudied (Baró et al., 2021). More research is needed that considers these multiple factors simultaneously.

Our study will fill these research gaps by inventorying how often students use urban green school grounds for nature-based activities, and factors that influence increased participation in nature-based activities by students. We compared nature-based activities with traditional outdoor activities. We first explored factors that influence students’ awareness of nature-rich green spaces (i.e. gardens and woodlands) because students likely do not engage in nature-based activities if they do not know that nature-rich green spaces exist on schoolyards. We hypothesized that students’ awareness of nature-rich green spaces would be (1) positively related to the frequency of teacher taking students outdoors, and (2) positively related to teachers’ professional development, measured by whether the teacher had environmental education (EE) training. We also used the same factors to exam the effect on students’ awareness of traditional outdoor spaces (i.e. playground and athletic fields) and hypothesized that none of above factors would be positively related to the awareness of either of the traditional outdoor spaces. Second, we compared the frequency of spending time in nature-rich areas (i.e., gardens and woodland), with traditional outdoor activities of playing sports and recess. We hypothesized that the frequency of students playing in nature-rich areas would be (1) positively related to the frequency of teacher taking students outdoors, (2) positively related to teachers’ professional
development in EE, and (3) positively related to students’ positive attitudes towards schoolyards that are good as learning places. In contrast, we hypothesized that the frequency of students participating in traditional outdoor activities would not be related to any above variables. In addition, we controlled for schools’ physical environment (i.e. total green space, and whether a school has gardens or woodlands) and students attribute of gender, age and ethnicity.

3.2 Methods

3.2.1 Study sites

We chose the City of Raleigh, North Carolina, as our study site, one of the fastest growing urban areas in the US (Inkiläinen, McHale, Blank, James, & Nikinmaa, 2013). Public elementary schools within the City of Raleigh were from the largest school district, Wake County Public School Systems (WCPSS), in North Carolina. We focused on elementary school students (from 3rd to 6th grade) because elementary school students are more likely than older students to be outdoors during compulsory school time (Pagels et al., 2014). Additionally, time in nature as young children may be likely to ensure lifelong benefits (Cheng & Monroe, 2012; Wells & Lekies, 2006).

We targeted four green space types that were commonly seen in urban schoolyards. We split them into two groups, nature-rich green spaces including (1) gardens for growing flowers, herbs, vegetables or fruits; and (2) woodlands, natural or semi-natural green spaces dominated by trees; and traditional outdoor spaces including (3) playgrounds, green spaces with recreational facilities (e.g. playground slides, climbers) and (4) lawn athletic fields (e.g. soccer fields) (Fig. 1). Here, we conceptualize nature-rich areas as those that support nature-based activities such as playing with natural elements (e.g. branches, flowers), exploring, or observing nature.
(Herrington & Brussoni, 2015; Raith, 2017). We acknowledge that some of these areas may not be nature-rich in an ecological sense (e.g., high diversity or species richness [Brown et al., 2007]), but instead, we are interested in opportunities for students to interact with nature. Traditional outdoor spaces support casual outdoor physical activities such as playing sports and recess (Aminpour et al., 2020), but typically do not encourage nature-based play. We recorded the presence and absence of the four green space types from schools that participated in our study by site visit in summer 2018.

Aside from the presence of green space types, we also include a variable that controls for the amount of non-impervious surfaces at the school to represent green space areas on school grounds. We used 2016 color infrared (CIR) imagery (1 m resolution originally, resampled to 5 m to fit the computational capacity) from the National Agriculture Imagery Program (NAIP) to classify land cover on each school ground (USDA, 2016). The classification scheme included 5 land cover types included bare soil, lawn/grass/herbaceous, impervious surfaces, tree canopy and water, based on HERCULES (Cadenasso et al., 2007). We used a supervised classification algorithm, Random Forest, to classify the land cover of school ground (Hayes et al., 2014). The classification was conducted in R 3.4.2 (R Core Team, 2014).

3.2.2 Survey data collection

To understand how students were using their schoolyards and what factors might influence that use, we conducted surveys with both students and teachers. To begin, we sent out an invitation email to 3rd to 6th grade teachers (n = 1023) across WCPSS. In the invitation email, we included a recruitment letter and a link to a Qualtrics survey for teachers. We then contacted the 42 teachers who showed interest (4.1% response rate) with a link to the Qualtrics
survey for students and asked them to administer it. Of those 42 teachers, 14 teachers from 9 schools committed to administer the survey to students (33.3% compliance).

Surveys for students were administrated via an online survey using the Qualtrics platform. Many teachers (n = 10) chose to administer the surveys during class time. Each student was given a device with the online survey, and teachers were available to clarify meaning of the questions and discourage discussion of responses among students. A handful of teachers (n = 4) instead chose to provide students with a link to the online survey to complete at home. A total of 228 students corresponding to 14 teachers from 9 schools completed the questionnaire, with the completion rate from 17% to 100% (mean completion rate = 98.6%). Since the pilot data indicated that the survey needed minimal revision, we included that data in the final analysis. We excluded responses with completion rates below 50%, resulting in an effective sample size of 199, with the power of 0.92 at α < 0.05 level (Cohen, 1988; Miguel Cruz & Guarín, 2017). The summary of teacher and student demographics is shown in Table 3.1.
Table 3.1. Demographics of teachers and students who finished survey. Data is displayed in percentage.

<table>
<thead>
<tr>
<th></th>
<th>Teachers (14 teachers in 9 schools)</th>
<th>Students (199 students in 9 schools)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grade</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3th</td>
<td>7.1</td>
<td>11.4</td>
</tr>
<tr>
<td>4th</td>
<td>57.1</td>
<td>41.6</td>
</tr>
<tr>
<td>5th</td>
<td>28.6</td>
<td>39.1</td>
</tr>
<tr>
<td>6th</td>
<td>7.1</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female/Girls</td>
<td>92.9</td>
<td>59.2</td>
</tr>
<tr>
<td>Males/Boys</td>
<td>7.1</td>
<td>40.8</td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>92.9</td>
<td>34.8</td>
</tr>
<tr>
<td>Black</td>
<td>7.1</td>
<td>20.1</td>
</tr>
<tr>
<td>Hispanic</td>
<td>-</td>
<td>14.0</td>
</tr>
<tr>
<td>Asian</td>
<td>-</td>
<td>3.4</td>
</tr>
<tr>
<td>Pacific islander</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Native American</td>
<td>-</td>
<td>2.9</td>
</tr>
<tr>
<td>Two or more</td>
<td>-</td>
<td>8.3</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>15.2</td>
</tr>
</tbody>
</table>

3.2.3 Survey instrument

The first set of questions measured students’ awareness of the four green spaces. We used pictures from school site visits to generate examples of each type of green space and asked students if they had seen similar features in their schoolyards (Figure 3.1). Each picture was displayed in color and with a brief description (e.g., a garden with mostly vegetables or flowers). To understand the use of schoolyards, we asked students, “How often do you do the following activities in your schoolyard?” In this question, we included two traditional outdoor activities in schoolyards (i.e. playing sports and recess) and two nature-based activities (i.e. spending time in gardens, exploring woodlands). Though we acknowledge that some of these activities may overlap (e.g., recess with other categories), we included each separately in the model to isolate
independent effects. This also allows us to ensure that low participation in one activity (e.g.,
exploring woodlands) was explained by little time for recess in general. We measured frequency
of participation in each activity on a 1-5 scale (i.e. never, once or twice a year, about once a
month, about once a week, several times a week or more). We also asked students about their
perception of each type of green spaces as a place for learning (i.e. “Do you think the following
places would be a good place to learn?”) and measured their agreement in 1-5 scale from
strongly disagree to strongly agree. To capture whether teachers’ professional development
background would influence children’s activities, we asked teachers whether they had attended
an EE professional development workshop before. Then we asked teachers how frequently they
take students outdoors for class time, measured on the same 1-5 frequency scale as on the student
instrument. In the survey, students were asked to self-identify race according to the following
categories, as was consistent to the school district’s designation of student race and ethnicity:
(1) White, (2) Black, (3) Hispanic, (4) Asian, (5) Pacific Islander, (6) Native American, (7) Two
or more and (8) other. All students’ answers were collected anonymously, but we asked the name
of their teachers in order to pair students with teachers in analysis. For survey detail, see S1 and
S2.
Figure 3.1. Four green space types measured in schoolyards.

3.2.4 Data analysis

First, we calculated the mean awareness of each green space type among students and teachers. Next, examined the frequency of each type of activity by demographic (i.e., age, race/ethnicity, and gender). To facilitate hypothesis testing, we used logistic regression (family = binominal) to model the students’ awareness of three types of nature-rich green spaces (i.e. garden and woodland; aware = 1, not aware = 0) as a function of the frequency of teachers taking students outdoors and teachers’ professional development background. Similarly, we coded teachers’ professional development in EE as bivariate (yes = 1, no = 0). A random effect for teachers was included because students from the same classroom may have similar awareness and behaviors on school grounds. We also controlled whether schoolyards had a given type of green space (corresponding green space presence = 1, absence = 0), the gender (boys = 0, girls = 1), race/ethnicity, and grade. The race/ethnicity was recoded into four groups (White = 0, Black = 1, Hispanics = 2 and Others = 3) because the distribution of responses were such that most
students identified as one of the first three categories, and also the sample size did not allow more fine-grained groupings. We realized that this approach could be seen as socially problematic, but it allowed us to examine variation across race at as granular a level as our sample allowed. None of demographic information was significant, so we excluded these to prioritize parsimony.

Then we used multiple linear regression to model the student’s use of each type of nature-rich green space (woodland and garden) and students participating in traditional outdoor activities (playing sports and recess) as a function of the frequency of teachers taking students outdoors, teachers’ professional development background, and students’ attitude towards greenspace as places for learning. We also controlled students’ demographic background, the presence of the relevant green space by including a variable denoting presence on the associated schoolyard and green space areas of each schoolyard. The model included a random effect for teacher as well. As grade was not a significant factor in models, we removed it from the final model.

### 3.3 Results

#### 3.3.1 Green spaces in schoolyards and corresponding awareness

Among the 9 schools that participated in our study (n=9), 3 schools had woodlands (33.3%) and 6 schools had gardens (66.7%) (Table 3.2). In comparison, all schools (100%) had athletic fields and 8 schools (89%) had playgrounds. The average green space areas was 59.68% (SD = 12.55%) (Table 3.2, for detailed land cover, see Table S3). Students were most aware of playground and athletic fields with students correctly identifying their presence over 70% of the time. In schools with gardens, 68.9% students were aware gardens existing in their schoolyards.
Less than 30% of students identified woodlands in their schoolyards. The awareness of different green spaces was higher among teachers. Almost all teachers knew if their schools had gardens, as well as playgrounds and athletic fields. However, only 66.7% teachers were aware if their school had a woodland.

Table 3.2. School information including the number of students and teachers participated in the survey from each school and the presence of green spaces information in schools (1 = exist, 0 = no).

<table>
<thead>
<tr>
<th>School code</th>
<th>Number of teachers</th>
<th>Sample of students</th>
<th>Total number of 3-6th students at school</th>
<th>Proportion of 3-6th students sampled</th>
<th>Sampled grade</th>
<th>Garden</th>
<th>Wooded areas</th>
<th>Playground</th>
<th>Athletic field</th>
<th>Green space areas in percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>32</td>
<td>313</td>
<td>10.2</td>
<td>5th</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>69.7</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>22</td>
<td>310</td>
<td>7.1</td>
<td>4th</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>75.1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>10</td>
<td>458</td>
<td>2.2</td>
<td>4th</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>63.2</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>35</td>
<td>228</td>
<td>15.4</td>
<td>5th</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>47.0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>5</td>
<td>144</td>
<td>3.5</td>
<td>4th</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>55.2</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>25</td>
<td>211</td>
<td>11.8</td>
<td>5th</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>39.8</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>23</td>
<td>321</td>
<td>7.2</td>
<td>3th</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>62.1</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>31</td>
<td>239</td>
<td>13.0</td>
<td>4th</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>75.0</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>16</td>
<td>368</td>
<td>4.3</td>
<td>6th</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Average green space areas in percentage (SD) | 59.68 (12.55)

Proportion of schools where present (n=9) | Proportion of students identifying presence (SD) | Percentage of teachers identifying presence (SD)

3.3.2 Descriptive statistics for outdoor activities

Self-report results showed that students participated in nature-based activities much less frequently than traditional outdoor activities like sports and recess (Figure 3.2). Recess was the most frequent activity in which students participated in their schoolyards (several times a week.
on average), followed by playing sports (close to once a week). Activities with the lowest frequency were exploring woodlands (less than once or twice a year on average) and spending time in gardens (less than once a month). For those two nature-based activities, we found that the reported frequency was slightly higher among girls than boys. In contrast, boys reported higher frequency in playing sports than girls. Compared to other grades, 6th grade students reported the lowest frequency related to nature-based activities (less than once or twice a year).

**Figure 3.2.** Frequency of students’ self-report activities in their schoolyards by gender, race/ethnicity and grade, coded in 1-5 scale (Never, Once or twice a year, About once a month, About once a week, Several times a week) with 95% confidence interval.
3.3.3 Regression models

We found only partial support for our hypothesis that teachers who took students outdoors and had training in EE was positively related to student awareness of nature-rich areas on schoolyards, as distinct combinations of teachers’ attributes enhanced awareness of gardens and woodlands (Table 3.3). We found that frequency of teachers taking students outdoors ($p < 0.05$) and EE training ($p < 0.1$) were positively correlated to the student awareness of gardens. Both the presence of garden and more green space areas were also found to be positively correlated to the awareness of gardens. However, only presence of a woodland was a significant factors of student awareness ($p = 0.05$), as neither teacher attribute was significant. Different from assumption, teachers’ EE workshop experience was not a significant factors of student awareness of traditional outdoor spaces. No correlation was found between green space areas and student awareness of woodland. However, students were less aware of playgrounds when their teachers took them outdoors frequently ($p < 0.05$). Neither of the controlled green space variables was positive correlated to student awareness of traditional outdoor spaces.

We also found partial support for our hypothesis that teachers taking students outdoors for class and having training in EE would increase student use of nature-rich areas (Table 3.4). Although neither teacher attribute factor was related to students spending time in gardens, we found that teachers who had EE professional development was positively related to students exploring woodlands ($p = 0.04$). Student responses that woodlands were “a good place to learn” were positively related to exploring woodlands ($p = 0.07$). In contrast, we did not find either teacher attribute to be related to the traditional activities. Regarding to the controlled green space variables, we found that the green space areas were positive correlated to spending time in gardens but not exploring woodlands. For traditional activities, the green space areas was found
to be positively associated with recess but not with playing sports. We found that boys were more likely than girls to report that they played sports (p = 0.01) but less likely to report spending time in gardens than girls. Black students reported playing sports more frequently than rest of other race/ethnicity. Students identifying as Hispanic students reported less frequent recess than white students (p = 0.06).

**Table 3.3.** Predictors of the awareness of green space types in schoolyards among students (n = 199), including a nested random effect for teachers in generalized regression model.

<table>
<thead>
<tr>
<th>Green spaces</th>
<th><strong>Variable</strong></th>
<th><strong>Beta</strong></th>
<th><strong>SE</strong></th>
<th><strong>p</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Garden</td>
<td>Frequency taking kids outdoor</td>
<td>0.41</td>
<td>0.13</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>0.56</td>
<td>0.35</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Garden presence</td>
<td>2.65</td>
<td>0.47</td>
<td>0.00001</td>
</tr>
<tr>
<td></td>
<td>Percentage non-impervious surface</td>
<td>7.20</td>
<td>2.51</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td><strong>R(^2)</strong></td>
<td></td>
<td></td>
<td>0.399</td>
</tr>
<tr>
<td>Woodland</td>
<td>Frequency taking kids outdoor</td>
<td>0.28</td>
<td>0.31</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>-0.10</td>
<td>0.64</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Woodland presence</td>
<td>1.53</td>
<td>0.57</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>4.40</td>
<td>3.34</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>R(^2)</strong></td>
<td></td>
<td></td>
<td>0.162</td>
</tr>
<tr>
<td>Athletic field</td>
<td>Frequency taking kids outdoor</td>
<td>-0.21</td>
<td>0.16</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>-0.27</td>
<td>0.45</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Athletic field presence</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>3.92</td>
<td>2.76</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>R(^2)</strong></td>
<td></td>
<td></td>
<td>0.09</td>
</tr>
<tr>
<td>Playground</td>
<td>Frequency taking kids outdoor</td>
<td>-0.31</td>
<td>0.13</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>0.18</td>
<td>0.41</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Playground presence</td>
<td>2.51</td>
<td>0.74</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>-1.28</td>
<td>2.34</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td><strong>R(^2)</strong></td>
<td></td>
<td></td>
<td>0.17</td>
</tr>
</tbody>
</table>
Table 3.4. Factors of activities among students, including a nested random effect for teachers.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Variable</th>
<th>Beta</th>
<th>SE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spend time in gardens</strong></td>
<td>Frequency taking kids outdoor</td>
<td>0.17</td>
<td>0.23</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>0.35</td>
<td>0.51</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Learn in gardens</td>
<td>0.04</td>
<td>0.06</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Garden presence</td>
<td>0.18</td>
<td>0.58</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>5.68</td>
<td>2.74</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Gender: Boys</td>
<td>-0.35</td>
<td>0.16</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Race: Black</td>
<td>0.2</td>
<td>0.24</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Hispanic</td>
<td>-0.14</td>
<td>0.28</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Other</td>
<td>-0.03</td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.357</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Explore woodlands</strong></td>
<td>Frequency taking kids outdoor</td>
<td>0.08</td>
<td>0.09</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>0.71</td>
<td>0.35</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Learn in wood</td>
<td>0.15</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Woodland presence</td>
<td>0.35</td>
<td>0.49</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>0.18</td>
<td>1.54</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Gender: Boys</td>
<td>-0.07</td>
<td>0.22</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Black</td>
<td>0.43</td>
<td>0.34</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Hispanic</td>
<td>-0.11</td>
<td>0.41</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Other</td>
<td>0.52</td>
<td>0.28</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.156</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Playing sports</strong></td>
<td>Frequency taking kids outdoor</td>
<td>-0.03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>EE workshop experience</td>
<td>-0.1</td>
<td>0.36</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Learn in athletic field</td>
<td>0.05</td>
<td>0.08</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Athletic fields presence</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Percentage of non-impervious surface</td>
<td>-0.17</td>
<td>2.30</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Gender: Boys</td>
<td>0.50</td>
<td>0.21</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Race: Black</td>
<td>0.74</td>
<td>0.31</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Race: Hispanic</td>
<td>0.08</td>
<td>0.35</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Race: Other</td>
<td>0.25</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.170</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.4 (continued).

<table>
<thead>
<tr>
<th></th>
<th>Frequency taking kids outdoor</th>
<th>EE workshop experience</th>
<th>Learn in playground</th>
<th>Playground presence</th>
<th>Percentage of non-impervious surface</th>
<th>Gender: Boys</th>
<th>Race b: Black</th>
<th>Race: Hispanic</th>
<th>Race: Other</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recess</td>
<td>-0.03</td>
<td>0.09</td>
<td>-0.02</td>
<td>0.16</td>
<td>1.27</td>
<td>0.08</td>
<td>0.19</td>
<td>-0.25</td>
<td>0.05</td>
<td>0.121</td>
</tr>
</tbody>
</table>

3.4 Discussion

3.4.1 The presence of green spaces in schoolyards

Unsurprising, the presence of nature-rich areas, especially woodlands, is less common than traditional outdoor playground in our study. The absence of wooded areas within school properties is also found in other studies, whereas the lawn covered spaces is the dominant green space type across US and some European countries (Baró et al., 2021; Kuo et al., 2021; Lindemann-Matthies & Köhler, 2019; Long, 2004; Schulman & Peters, 2008). The lack of wooded areas in schoolyards is the result of many concerns including neatness, safety (Lindemann-Matthies & Köhler, 2019), the cost of maintenance (Iojá et al., 2014), and the need for sports and running activities (Long, 2004; Schulman & Peters, 2008). The variance of green space types across 9 schools may indicate the potential greenness inequity, though based on our small sample size, we caution drawing such inferences. However, existence of athletic fields and playgrounds is likely the result of consistent landscape design, highlighting how greenness is not often explicitly included in landscape planning for school grounds (Schulman & Peters, 2008). In our study, according to WCPSS Learning Environment Guideline, for example, each
elementary schoolyard should have a sports field and a playground (WCPSS, 2020b). However, there is no school district level standard for vegetation cover, which may affect the presence of nature-rich areas across schools. As previous study suggested that school-based exposure to green space was uneven across the urban of Barcelona that greener schools tend to be associated with wealthier neighborhoods (Baró et al., 2021), we have the reason to show some concern about the distribution of nature-rich areas in our study.

3.4.2 The awareness and the use of green spaces in schoolyards

While previous research has suggested that children would use green elements when they were present (Baró et al., 2021), we found that the presence of nature-rich green space in urban schoolyards does not necessarily guarantee awareness or high frequency of use. As discussed above, the relatively low absence of nature-rich areas compared to sports fields and lawns may be one of the reasons limiting use of green spaces (Baró et al., 2021). However, when nature-based areas were present, they did not always translate to awareness, specifically in relationship to woodlands. One way to interpret these findings is that teachers and students may find schoolyards with more green space more attractive (Lucas & Dyment, 2010), leading children to go out more, which could link to the awareness and use of gardens. Further, there is some evidence children prefer areas with tidy green spaces with diverse species (e.g., gardens) (Lindemann-Matthies & Köhler, 2019) or use green spaces near buildings and the edge of green space because these spaces are able to support light activities, games, and social interaction with peers (Aminpour et al., 2020; Mårtensson et al., 2014). However, other evidence suggests that children prefer extensive natural settings (e.g., forest and woodland) that allow for more unstructured play (Laaksoharju & Rappe, 2017; Mårtensson et al., 2014), which may suggest that
the limited use of woodlands may be linked with decisions of adults rather than students. For instance, physical inaccessibility (e.g., undergrowth, fences), or factors related to school policies, such as not allowing children to play in these areas, may prevent children from using these areas or knowing they exist. Further, though we do not know whether children were involved in the schoolyard design process, this dynamic is rare (Woolner, Hall, Wall, & Dennison, 2007). Research suggests that participation can increase the meaning and attachments of a place, making a place emotionally charged for children, and children are more likely to use and care for the place when they are involved in creating process (Chawla et al., 2014; Derr & Rigolon, 2015; Moore & Wong, 1997).

Given the possibility that students are not able to access green areas on their school grounds even when those areas are present, it is not surprising that the biggest factors affecting student use are related to teachers. Our study finds that teachers taking children outdoors frequently increases the likelihood that they will be aware of gardens, that teacher professional development in EE promotes use of natural areas by students, and that students seeing woodlands as a good place to learn increases their chances of spending time there. From this, we see that teacher preparation and facilitation of outdoor spaces is important to encouraging student use of these spaces. In some cases, teachers may even make students more aware of natural areas than traditional playgrounds. Accordingly, teachers may act as gatekeepers, and as a corollary, facilitators of use of natural areas, either through classroom policies (e.g., allowing students to play in these areas), or direct facilitation (E.g., class activities in these areas) (van Dijk-Wesselius et al., 2020).

As teachers seem to be key to affect use of natural areas, professional development aimed at equipping teachers with the knowledge, skills, and experience to encourage outdoor learning
and play may translate to use of natural areas by students. We saw in our results that teachers trained in EE were more likely to have students that spent time in natural areas in schoolyards. This is consistent with previous research and may be explained by several mechanisms. Teachers commonly cite barriers to taking students outdoors including low knowledge of school ground plants (Akoumianaki-Ioannidou et al., 2016; van Dijk-Wesselius et al., 2020) and little experience and expertise teaching in natural outdoor settings (Ernst, 2014; van Dijk-Wesselius et al., 2020). Others have found that teachers are unaware of the benefits associated with taking students outdoors (Akoumianaki-Ioannidou et al., 2016). Professional development has been shown to address these barriers by building content knowledge and activity ideas, as well as building teacher confidence and motivation to implement outdoor learning (Ernst & Erickson, 2018). For example, a professional development program designed to help teacher using schoolyards for teaching science and math in Indonesia increased teachers’ knowledge and skills in designing outdoor learning activities (Koto & Susanta, 2019). Similarly, a study assessed “A River Runs Through it”, an environmental professional development program, and found that the program helped teachers bring outdoor experiences and knowledge back to their own classrooms (Sondergeld, Milner, & Rop, 2014). Many professional development programs offer outdoor learning training such as Project Learning Tree (Sustainable Forestry Initiative Inc., 2019), NatureStart (Chicago Zoological Society, 2019), and Ecology Project International (2019). They are potential sources to support teachers using green schoolyards by incorporating outdoor learning in existing curriculum (van Dijk-Wesselius et al., 2020).

In particular, low teacher awareness of woodlands as well as low student use suggests that professional development may need to be paired with landscape and policy changes to promote use of woodlands by teachers and students. The higher levels of garden awareness and
use is encouraging, as efforts to expand school gardening and encourage gardens as learning tools have been developing for decades (Blair, 2009), including in our study site (WCPSS, 2020a). Compared to gardens, woodlands may be less used because of safety concerns (Laaksoharju & Rappe, 2017). Trees may pose more risk of injury such as falling down when climbing or being hurt while playing with branches (Laaksoharju & Rappe, 2017). Woodlands may also have dense understories (e.g. shrubs and herbaceous cover) without clear pathways for children to navigate. Accordingly, woodlands may be perceived as inappropriate or unsafe places for playing or learning (Jansson et al., 2014). This is unfortunate, given the growing body of research documenting how exposure to trees provides particularly enhanced benefits related to physical health, mental well-being (Lee et al., 2011; Takayama et al., 2014), and academic performance (Kuo, Browning, Sachdeva, et al., 2018). As benefits of access to wooded areas may justify the risks, and several steps can be taken to mitigate potential or perceived risks (Ernst, 2014). For instance, adding clear trails, opening up a part of woodland by cleaning dense understory, setting benches under canopies, and planting colorful flowers at woodland edge may help mitigate safety concerns and promote the use of woodland (Li and Nassauer 2020).

Additionally, professional development for teachers and administrators on the benefits of woodlands, their safe use, and ways in which they can enhance instruction and student health and well-being may help encourage use of woodlands for teachers and students (Bloom et al., 2010).

Based on differences associated with student demographics, we suggest that green schoolyards may be a way to differentiate schoolyard spaces that meets all students’ needs. We found that girls and boys were just as likely to explore woodlands, consistent with research suggesting that natural areas can provide equitable and inviting play opportunities for all children (Änggård, 2011; Lucas & Dyment, 2010; Mårtensson et al., 2014). Research has shown that
natural features like trees and vegetables attract both girls and boys (Moore, 1986) and provide affordance for more diverse play (e.g. climbing a tree, running and chasing games) to both genders (Ãnggård, 2011; Jansson et al., 2014). Boys reported higher frequency in playing sports, whereas girls reported slightly higher frequency in nature-based activities, especially spending time in gardens. The trend that boys play more in lawn sports field is also found in other studies (Aminpour et al., 2020; Mårtensson et al., 2014), with implications for a potential gender gap with respect to physical activity (Mårtensson et al., 2014). Because girls seem to be more active than boys in natural areas, green schoolyards may help to mitigate health equity gap associated with traditional school ground by promoting physical activities among girls (Bikomeye, Balza, et al., 2021). In addition, we found that race/ethnicity was not related to use of natural areas. Many studies have documented and offered explanations for why people of color, and particularly those identifying as Black, may engage in less nature-based recreation (Ekenga, Sprague, & Shobiye, 2019; Rigolon, 2016). These have included less access to green spaces (Comber, Brunsdon, & Green, 2008) and high quality parks (Rigolon, 2016), which are the long-lasting legacy issue of systemic and historic discrimination and racism such as racially discriminatory land use and housing policies that shape residential geographies and cause inequity (Floyd, 2014; Rigolon & Németh, 2018). Our results are consistent with research demonstrating that when barriers and injustices in access to urban green space are addressed, racial differences in engagement with nature disappear, strengthening the case for green schoolyards as a mechanism to provide equitable access to nature and its benefits (Stevenson et al., 2020). As our study represents a small sample of students, future research should continue to explore these questions.
3.4.3 Limitations and future study

There are some limitations to our study. For instance, studies with larger numbers of students or schools may find that nascent relationships found here (e.g., age), may be significant with a larger sample (e.g., Raith 2017), as well as allow for exploration of whether our findings are generalizable in other urban contexts. Additionally, though we launched our survey during leaf-on season, some features such as flowers and vegetables may be limited in a short amount of time that can influence students’ awareness of some type of green space. Additionally, though the integration of teacher and student perspectives with landscape attributes is novel, the measurement may be limited. For example, we only measured the "spending time in gardens" or "exploring woodlands" as nature-based activities in schoolyards, as we balanced wording that students could understand, parsimony in the survey design, and reflection of the literature (Fanning, 2005). Further, it is possible that the pictures in survey, meant to be illustrative examples, caused students especially to more narrowly define these areas so that they reported not having them when they actually did. Future research may ameliorate this possibility by integrating direct observation of student and teacher use as behavior measurement, as self-reported behavior may be inaccurate, particularly among children (Teye and Peaslee 2015).

In addition to these limitations, we can identify several areas for future research. First, we encourage researchers to continue to examine multiple factors in predicting the implementation and use of green schoolyards. In particular, attention to the distribution of green schoolyards, with an eye toward providing equitable access may be particularly useful. Though our sample was too small to draw conclusions directly related to our study, the variation in green area across school grounds raises concern. We consider green schoolyards to be a promising source for promoting equal access to nature and its benefits, as many health disparities
linked to poverty (e.g., lower physical activity, higher stress levels) also correlate with access to
natural areas, which have been linked to health benefits (Bikomeye, Balza, et al., 2021).
Similarly, research targeting investment in green schoolyards in poorer school districts to
increase equitable access to green space, as well as pairing these efforts with longitudinal
research on potential impacts on equitable benefits related to health and other outcomes is
needed. These efforts could also be linked to broader cost-benefit analyses. A frequently cited
barrier to green school yards is the cost of implementation and maintenance (Iojă et al., 2014).
However, given the potential for green schoolyards to provide the myriad of benefits associated
with significant investments (e.g., health outcomes, climate change adaptation: Bikomeye et al.,
2021b, 2021a), a broad view of both the benefits of green schoolyards may be warranted.

3.5 Conclusion and Recommendations

Our research demonstrates that the existence, awareness, and use of nature-rich areas on
schoolyards is substantially lower than that of traditional schoolyard features, but that teachers
can play a considerable role in unlocking the benefits that do exist on school grounds. We
suggest that efforts to green schoolyards in urban areas should continue, but that integrating
teacher professional development and associated engagement with administration is necessarily
to ensure use by teachers and students. These findings are consistent with recommendations from
the Children & Nature Network, a major leader of the green schoolyards movement in the United
States, which emphasizes that green schoolyards should be designed by or with input from
students, teachers, and community members (Children & Nature Network, 2016). By providing
teachers with opportunity for input on schoolyard design, teachers may be more likely to take
students outdoors during class, which may build awareness of the natural areas. Additionally,
professional development can facilitate use of outdoor spaces as dynamic places for learning as well as increase teachers’ comfort in facilitating and supervising student use of natural areas (Bloom et al., 2010; Ernst, 2014). Finally, urban green schoolyards can be seen as an opportunity to create inclusive school grounds that serve all children, regardless of gender or race/ethnicity, and provide the large array of benefits associated with nature.
CHAPTER 4. Use of Nature-Based Schoolyards Predicts Students’ Perceptions of Schoolyards as Places to Support Learning, Play, and Mental Health

Zhenzhen Zhang, Kathryn T. Stevenson, Katherine L. Martin

Abstract

Although green schoolyards provide many benefits to children and communities, little research explores students’ perceptions of these benefits and how natural elements (e.g., gardens, trees) and associated use shape students’ experience. We examine the relationship between nature-based attributes, nature-based activities, and teacher-led activities with students’ perceptions of schoolyards’ benefits to self (e.g., feeling calm, good place to learn) and to community (e.g., contributions to cleaner water, increased biodiversity). We measured 199 3rd - 6th grade students’ perceptions of schoolyards’ benefits from 9 schools in Raleigh, North Carolina. Overall, students positively viewed schoolyards, and recognized more benefits to self than community. We found that relationship between the presence of nature-based attributes and students’ positive feelings was limited. Instead, we found that nature-based activities and teacher-led activities had a positive relationship with positive feelings. Findings suggest that school greening efforts need to be paired with policies and curricular practices to encourage interaction with natural elements to ensure benefits are fully realized by students.

4.1 Introduction

As most students spend about 20-30 hours at schools every week throughout their childhoods (National Center for Education Statistics, 2018; Perie, 1997), school environments have a significant influence over the lives of children and youth. Though many consider the primary purpose of schools is to build knowledge and skills around subjects such as mathematics,
language arts, or science (Spillane, Diamond, Walker, Halverson, & Jita, 2001), childhood school years (ages 5-18) are an important developmental stage in a host of areas. For instance, this age range is when children establish their academic abilities, develop decision-making and communication skills, as well as acquire attitudes toward self, family, peers, and society (American School Counselor Association, 2017; Pell & Jarvis, 2001). Accordingly, students’ experiences in schools can have considerable influence over academic, as well as emotional, social, and behavioral outcomes well into adulthood (Olsson, McGee, Nada-Raja, & Williams, 2013).

Because the time students spend in school can be so influential on many aspects of youths’ lives, promoting positive school environments is of the utmost importance. For instance, the social and emotional environment, including support from teacher-student relationships and peer relationships, has been linked to school engagement and academic performance (Bergin & Bergin, 2009; Ladd, Buhs, & Seid, 2000). The physical environment can affect the school experience as well. For example, aspects of the physical classroom environment such as air quality, noise and lighting, and amenities such as chairs and desks can influence students’ academic performance (Suleman, Aslam, & Hussain, 2014); school environments with litter, graffiti, and disrepair have been associated with students’ perceptions of school violence (Johnson, 2009). Several studies also demonstrate how these factors can influence one another. For instance, school classrooms with informal spaces for gathering and mobile amenities (e.g. movable desks and chairs, round tables) can promote interaction between students (Parsons, 2018). Similarly, a classroom without dedicated instructor space can encourage more interaction between students and teachers compared with the traditional classroom with separated spaces (Rands & Gansemer-Topf, 2017).

In addition to school design and amenities inside the school building, a school’s outdoor environment can also influence children’s experiences and feelings. One area of research focuses
on green schoolyards, which refers to school grounds featuring natural elements such as gardens, nature play areas, trails, and outdoor classrooms (Bikomeye, Balza, et al., 2021; Children & Nature Network, 2016; Zhang, Stevenson, & Martin, 2021). Compared to traditional school grounds with dominated by asphalt and concrete or turf and a few trees (Dyment & Bell, 2008; Fjørtoft, 2004; Lindemann-Matthies & Köhler, 2019), green schoolyards have been shown to provide students with social, health and academic benefits (Children & Nature Network, 2018). Natural elements in green schoolyards support group play; for example, wooded areas can inspire curiosity and allow peers to play in groups and encourage each other to explore (Chawla et al., 2014). Similarly, nature-rich environments can encourage boys and girls to play together (Änggård, 2011), compared with traditional sports fields that tend to be dominated by boys (Dyment et al., 2009). Teachers can connect natural features to subjects as science, math and languages which makes class more interesting and fosters children’s curiosity to learn (Endreny & Siegel, 2009; Moore, 2014; van Dijk-Wesselius et al., 2020). The physical environment of schoolyards can also help relieve mental fatigue associated with long periods of classroom work. For instance, stress and mental fatigue can be mitigated to some degree simply by a green window view (D. Li & Sullivan, 2016). Similarly, students have reported feeling calm, peaceful, and relaxed when playing in natural environments (Chawla et al., 2014; Kelz et al., 2015).

Aside from benefits to students, the benefits associated with green schoolyards can be expanded to broader communities. Green schoolyards as a component of urban green space can provide ecosystem services such as improving air quality (Calderón-Contreras & Quiroz-Rosas, 2017), managing water (Flax et al., 2020), and enhancing ecological functions (Iojă et al., 2014) beyond school boundaries. Some specific natural features like school gardens can be part of urban agriculture and enhance a city’s food system (Flax et al., 2020). However, these benefits to
community benefits are less recognized compared to benefits to self (Larson et al., 2016). As evidence suggesting that interacting with nature can enhance students’ environmental knowledge, attitudes (e.g., plants and animals are important), and behaviors (e.g., saving water, talking to others about the importance of protecting the environment) (Collado, Corraliza, Staats, & Ruíz, 2015; Martin, 2003), the interaction with nature may help enhance students’ recognition of schoolyards’ benefits to broader communities.

Though the physical design of schoolyards has been linked to diverse benefits for students and communities, the use of schoolyards by students likely determines the degree to which those benefits are realized. Students’ schoolyard use patterns are most likely affected by decisions made by teachers. For example, horticultural activities encouraged by teachers such as sowing seeds, weeding, and harvesting produce can foster cooperation, build trust, and establish new friendships via group-based work (Kim, Park, & Son, 2014). Natural elements in schoolyards are ideal settings for theory-driven approaches such as inquiry-based learning (Acharya, 2018; Endreny & Siegel, 2009). For instance, students can learn earth science by analyzing the composition of soil samples collected from schoolyards if teachers chose to use outdoor settings for learning (Endreny & Siegel, 2009). In addition, teachers can adopt a more lively, sensory, and experimental teaching style when using green schoolyards as outdoor education settings for math, science, and art, which has been linked to deeper learning (van Dijk-Wesselier et al., 2020). Further, intentional use and instruction can also help facilitate an understanding of how schoolyards can serve larger ecological purposes (Martin, 2003).

The diverse benefits that green schoolyards can provide are increasingly well understood; however, one understudied perspective is that of students themselves. Most research focused on students’ perception of green schoolyards’ benefits related to themselves, such as perceived
restorativeness (e.g., attentional restoration) (Bagot, Allen, & Toukhsati, 2015; van Dijk-Wesselius et al., 2018), self-perceived general health (Bikomeye, Balza, et al., 2021), playing (Malone & Tranter, 2003), learning (Benfield, Rainbolt, Bell, & Donovan, 2015), and attractiveness (Lindemann-Matthies & Köhler, 2019; van Dijk-Wesselius et al., 2018). Few studies address the students’ perception of benefits to communities such as the beauty of nature (naturalness) (Raith, 2017; van Dijk-Wesselius et al., 2018) and enhancing environmental quality. Understanding students’ perception of green schoolyards and associated benefits by students can help inform school administrators and landscape designers to better manage school outdoor environment for students’ benefit (Larson et al., 2016; Lindemann-Matthies & Köhler, 2019; van Dijk-Wesselius et al., 2018). Here, we draw on participatory frameworks introduced by Hart (1997) and others, and employed by many researchers and designers (Derr & Rigolon, 2015; Kreutz, Derr, & Chawla, 2018; Moore, 2014) that assert that engaging children in decision-making will create places that are meaningful to children (Hart, 1997). As pupils are the main stakeholders in schools, understanding their perceptions about the benefits of schoolyards and the use of different schoolyard components can ensure schools deliver a wide range of benefits to children. Further, children’s perspectives are important to guide future improvements and expansion of green schoolyards. Though empirical research linking the physical environment (e.g. tree cover) with objective student measures (e.g. test scores, physiological stress) is critical to build the evidence-based benefits of green schoolyards (Chawla et al., 2014; Kuo, Browning, Sachdeva, et al., 2018; Kweon et al., 2017b), including the perspectives of children can provide a nuanced understanding of how school design and use by students and teachers can shape the student experience.

We began to address these research needs by analyzing how the physical make-up of school grounds (e.g., presence of natural elements) and use by students shapes how students view their
own schoolyards. We included benefits to self, defined as students’ perceptions that schoolyards are attractive, and a good place to play, to learn, to help students feel calm, and to feel energized. We also included perceptions of benefits to community, defined as students’ perceptions that schoolyards provide key functions including wildlife habitat, a place to grow food, making the air and water cleaner, and reducing flooding. We hypothesize that students are more likely to perceive both benefits to self and community if natural elements (i.e. gardens, wooded areas) (a) are present and (b) used (i.e. looking at or playing with animals and plants, doing class activities in natural areas). Our aim was to understand how design and use of schoolyards shape students’ perceptions of schoolyard benefits, which could help ensure schoolyards are places students want to learn, play, and grow.

4.2 Methods

4.2.1 Schools and Participants

This research was conducted in Wake County Public School Systems (WCPSS), the largest school district in North Carolina, USA. We focus our study on elementary schools, as they are the main partners of many greening schoolyard programs, such as Space to Grow in Chicago (Space to Grow, 2016), San Francisco Unified School District’s Green Schoolyard Program (San Francisco Public Schools, 2017), and the Learning Landscape program in Denver (Anthamatten et al., 2011). Accordingly, the perspectives of elementary school children may be particularly useful to these and similar efforts.

We contacted 3rd to 6th-grade teachers from WCPSS (n = 1023) with an email invitation containing a link to the Qualtrics recruitment survey. The survey was approved by North Carolina State University Institutional Review Board for the use of Human Subjects in Research (IRB
We received responses from 42 teachers who showed interest (4.1% response rate). Among these teachers, 14 teachers from 9 schools agreed to participate in our research (33.3% compliance). Then, we visited schools that agreed to participate in summer 2018 and spring 2019 to collect school grounds information. We recorded the presence of two types of natural elements – (1) gardens with raised beds for growing flowers, herbs, vegetables, or fruits, (2) woodlands or forest (areas dominated by trees) (Figure 4.1). Among the 9 schools, there are 3 schools that have wooded areas and 6 schools have gardens (Table 4.1). All schoolyards have traditional outdoor features including playgrounds and athletic fields (for sports), but since they are not our focus, we did not include these features in the following analysis. Next, we requested that participating teachers administer a survey for students. Eleven teachers administer the survey during class time. During class, the teachers gave each student an electronic device (an iPad or a computer) with a link to the online Qualtrics survey. The remaining four teachers provided students with a link to the survey and asked students to complete the survey after school. We received 228 responses of students in total, with completion rate ranging 17% to 100% (mean = 98.6%). We excluded responses with less than a 50% completion rate, yielding 199 responses for analysis. The demographic information is shown in Table 4.2. As most students were identified as White, Black and Hispanic, we grouped self-reported race/ethnicity as Asian, Pacific Islander, Native American, Two or more, and Other into one category.

Figure 4.1. Nature-based attributes in schoolyards.
Table 4.1. The presence of nature-based features in schoolyards (1 = present, 0 = absent).

<table>
<thead>
<tr>
<th>School code (n=9)</th>
<th>Gardens</th>
<th>Wooded areas</th>
<th>Playgrounds</th>
<th>Athletic fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Proportion of schools where present (%) 66.7 33.3 88.9 100

Table 4.2. Summary of students (N = 199) and teacher (N = 14) participants for the survey.

<table>
<thead>
<tr>
<th></th>
<th>Portion of Students (%)</th>
<th>Portion of Teachers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grade</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3th</td>
<td>11.6</td>
<td>7.1</td>
</tr>
<tr>
<td>4th</td>
<td>41.2</td>
<td>57.1</td>
</tr>
<tr>
<td>5th</td>
<td>39.2</td>
<td>28.6</td>
</tr>
<tr>
<td>6th</td>
<td>8.0</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girl/Female</td>
<td>59.3</td>
<td>92.9</td>
</tr>
<tr>
<td>Boy/Male</td>
<td>40.7</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>Races/Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>35.7</td>
<td>92.9</td>
</tr>
<tr>
<td>Black</td>
<td>20.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Hispanic</td>
<td>13.6</td>
<td>-</td>
</tr>
<tr>
<td>Other a</td>
<td>30.2</td>
<td>-</td>
</tr>
</tbody>
</table>

*a “Other” included self-reported race/ethnicity as Asian (3.5%), Pacific Islander (1.0%), Native American (1.0%), Two or more (8.0%), and Other (14.6%).

4.2.2 Survey instrument

To understand students’ perception of schoolyards, we measured several benefits to self and benefits to community, drawing items from a previous study that measured public perceptions of the benefits of greenways by Larson et al. (2016). The benefits to self are related to students’
direct experience in schoolyards such as playing and learning. The benefits to community are key functions that schoolyards can provide to the overall environment. Specifically, we asked students “How much do you agree or disagree with the following statements?” Students provided their agreement on a 1-5 scale Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) in answering “My schoolyard…” “…is a good place to play and learn”, “…makes me feel calm”, “…helps me feel energized”, and “…is attractive” (benefits to self) and “…is a good home for animals,” “…provides space to grow food,” “…helps make the air cleaner,” and “…helps make water cleaner,” and “…helps reduce flooding” (benefits to community) (Rosa, Profice, & Collado, 2018). To measure the frequency of activities, we asked students, “How often do you do the following activities in your schoolyard?” We included two nature-based activities: “look at or play with plants (e.g., pick flowers, lay in the grass)”, and “look at or play with insects or small animals” because student can do these activities with any vegetation present rather than relying on some specific nature-based features. We also included one teacher-led activity: “spend time outside for class activities.” Students answered how often they did each type of activity on a 1-5 frequency scale (never, once or twice a year, about once a month, about once a week, several times a week or more). We also asked students to self-report their gender, race/ethnicity, and grade level, as well as the name of their teacher. Beyond these demographic questions, all responses were anonymous. During the survey development, we asked several teachers to review it for readability and age appropriateness. Teachers agreed that the survey would be appropriate for students included in the study. As 3rd grade represented the lowest age group and highest potential for difficulty in understanding the questions, we also examined the responses difference between 3rd grade and higher grades using Mann-Whitney U test for non-normal distribution data. We found no significant difference between groups (Table S1). For survey detail, see S2.
4.2.3 Data analysis

Based on the procedure suggested by Costello and Osborne (2005), we conducted principal axis factor analysis (PAF) to identify the broader themes of schoolyards benefits. PAF was applied with the oblique rotation (“oblimin”) transformation and 25 iterations. The oblique rotation considered the correlation between identified factors (Costello & Osborne, 2005). The determination of the number of factors considered both Cattell's scree test and eigenvalue (> 1.0) (Auerswald & Moshagen, 2019; Cattell, 1966; Costello & Osborne, 2005). The scree test was based on the graphic of the eigenvalue by identifying the breakpoint where the eigenvalues decrease abruptly and flatten out (Costello & Osborne, 2005). The number of factors before the breakpoint was the number of factors to retain in the factor analysis. Cronbach’s α was also calculated to assess the reliability of each factor (Costello & Osborne, 2005; Ursachi, Horodnic, & Zait, 2015). We used the package “psych” (Revelle, 2020) in R (R Core Team, 2014) to conduct the factor analysis.

Following the PAF, we used linear regression models to examine students’ perception of schoolyards’ benefits to self and community as a function of the natural elements (i.e. woodlands and gardens), nature-based activities by students, and use lead by teachers. We also used linear regression models to examine benefit to self and to community as a function of natural elements and use by students and teachers to capture nuanced differences. We controlled the way that teachers administer the survey (in-class vs. online) for the delivery method. Since it wasn't significant, we left it out of the final model. We also controlled for students’ demographic background and a random effect for teachers in both models. We examined variance inflation factors (VIF) statistic to test for collinearity, and found measures within the acceptable range (Table S3).
4.3 Results

The factor analysis identified two factors fitting in the expected two-theme structure that we defined for benefits (to self and to community, Table 4.3). Benefits to self included 5 items that explained 14.0% variance, with the sum of squared loadings (eigenvalue) 1.36. Benefits to community also contained 5 items, and explained 22.0% variance, with the sum of squared loadings 2.25. It contained the measures related to the broader environment including making air cleaner, making water cleaner, helping to reduce flooding, providing a home for animals, and providing places for food. All items’ loadings were larger than 0.4, above the acceptable level in social science studies, indicating the two-factor structure fit our data well (Costello & Osborne, 2005). Although there was a cross-loading item “a good place to learn” with loadings higher than 0.20 for both factors, we kept this item because an educational benefit was important in the school context. Both categories had Cronbach’s alpha higher than the acceptable level (0.6-0.7) (Ursachi et al., 2015) indicating the reliability of the two-factor structure. The correlation between the two factors was 0.48 (p < 0.01).
Table 4.3. Students’ perceived benefits summary statistics with a broader benefits category from the factor analysis (n = 199).

<table>
<thead>
<tr>
<th>Benefits category, with specific benefits</th>
<th>Mean</th>
<th>SD</th>
<th>Factor A</th>
<th>Factor B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Schoolyards’ benefits to self</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Cronbach's α = 0.67)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A good place to play</td>
<td>3.95</td>
<td>1.03</td>
<td>0.643</td>
<td>-0.223</td>
</tr>
<tr>
<td>A good place to learn</td>
<td>3.83</td>
<td>1.18</td>
<td>0.433</td>
<td>0.390</td>
</tr>
<tr>
<td>Helping me feel energized</td>
<td>3.61</td>
<td>1.17</td>
<td>0.581</td>
<td>0.137</td>
</tr>
<tr>
<td>Helping me feel calm</td>
<td>3.36</td>
<td>1.17</td>
<td>0.400</td>
<td>0.184</td>
</tr>
<tr>
<td>Attractive</td>
<td>3.24</td>
<td>1.09</td>
<td>0.722</td>
<td>0.060</td>
</tr>
<tr>
<td><strong>B. Schoolyard's benefits to communities (Cronbach's α = 0.75)</strong></td>
<td>3.10</td>
<td>1.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A good place to grow food</td>
<td>3.47</td>
<td>1.22</td>
<td>0.173</td>
<td>0.408</td>
</tr>
<tr>
<td>Making air cleaner</td>
<td>3.30</td>
<td>1.11</td>
<td>-0.097</td>
<td>0.743</td>
</tr>
<tr>
<td>Home for animals</td>
<td>3.20</td>
<td>1.41</td>
<td>0.039</td>
<td>0.851</td>
</tr>
<tr>
<td>Helping reduce flooding</td>
<td>2.76</td>
<td>1.02</td>
<td>-0.021</td>
<td>0.720</td>
</tr>
<tr>
<td>Making water cleaner</td>
<td>2.75</td>
<td>1.05</td>
<td>0.052</td>
<td>0.785</td>
</tr>
</tbody>
</table>

Note: Agreement scale: 1 Strongly disagree, 2 Disagree, 3 Neither agree nor disagree, 4 Agree, 5 Strongly agree

In general, self-report results showed that students were more likely to identify benefits to self than benefits to community (Table 4.3). Students mostly agreed that their schoolyards were a good place to play (mean = 3.95; SD = 1.03), followed by a good place to learn (mean = 3.83; SD = 1.18) and helping them feel energized (mean = 3.61; SD = 1.17). On average, students disagreed that their schoolyards improved water quality (mean = 2.75; SD = 1.05) or reduced flooding (mean = 2.76; SD = 1.02). When examining factors of benefits to self and community as composite scores, we found that class activities (p < 0.01) and looking at or playing with plants (p < 0.05) were significant factors of benefits to self, but found no significant factors of perceived benefits to community associated with schoolyard attributes or use (Table 4.4). We found that boys perceived fewer benefits to community than girls (p < 0.05). We did not find differences in perception of benefits to self and to community across race/ethnicity.
Table 4.4. Regression models of benefits to self and benefits to the community as a function of schoolyards’ attributes and use, controlling students’ demographic (n = 199), including a nested random effect for teachers.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Schoolyards' benefits to self</th>
<th>Schoolyard's benefits to communities</th>
</tr>
</thead>
</table>
|                           | β  
| Nature-based attributes   |                             |                                       |
| Woodland                  | 0.09 ± 0.47                   | 0.13 ± 0.90                           |
| Gardens                   | 0.10 ± 0.48                   | 0.17 ± 0.97                           |
| Activities                |                               |                                       |
| Class activities          | 0.27 ± 0.12                   | 0.09 ± 0.17                           |
| Look at or play with plants | 0.15 ± 0.10                   | 0.06 ± 0.15                           |
| Look at or play with animals | 0.11 ± 0.12                   | 0.08 ± 0.17                           |
| Demographics c            |                               |                                       |
| Gender                    | -0.10 ± 0.29                  | -0.14 ± 0.40                          |
| Black                     | -0.08 ± 0.43                  | -0.01 ± 0.60                          |
| Hispanic                  | 0.006 ± 0.46                  | 0.009 ± 0.66                          |
| Other                     | 0.008 ± 0.35                  | 0.04 ± 0.48                           |
| R^2                       | 0.232 ± 0.35                  | 0.259                                |

b β is the standardized beta; SE is the standard error.

c The reference category for gender is girl; reference for race/ethnicity is White or Caucasian.

4.4 Discussion

Students in this study noticed potential benefits associated with schoolyards, especially benefits to self. That students see benefits to themselves from their schoolyards is encouraging, as positive feelings toward school in childhood can be beneficial to academic performance, social-emotional development, as well as long-term outcomes in adulthood (Olsson et al., 2013; Suleman et al., 2014). Students perceive the highest level of benefits associated with recreation and learning, which is aligned with the main role of school grounds as places for learning (Malone & Tranter, 2003) and playing (Dyment & Bell, 2008). That fewer students identified schoolyards as a benefit to broader communities is perhaps not surprising, and maybe explained in several ways. First, it
could be that the schoolyards in this study do have limited impact on broader benefits to the community (Schulman & Peters, 2008), in which case students’ perceptions match reality. Secondly, potential benefits to communities such as supporting wildlife habitat, regulating flooding or promoting cleaner water may be abstract and hard to observe at a school scale, especially for elementary school-aged children with limited capacity for abstract thinking (Syawaludin, Gunarhadi, & Rintayati, 2019). This latter explanation may be addressed with curricular interventions, with teachers facilitating clear conceptual links between schoolyard attributes and impacts on a broader community. For example, in one study, teachers used a schoolyard pond to help students learn about local environmental issues across a large watershed scale (Bodzin, 2008). By collecting, and measuring water samples from the pond in schoolyard over a semester, students were able to understand changes in macroinvertebrates as a biological indicator of water quality in a larger geographic scale (Bodzin, 2008). In this example, as well in our study, both the direct contact with natural elements (i.e., playing with plants) paired with facilitation by the teacher (i.e., class activities) are key factors to students’ perceptions of schoolyard benefits, suggesting that curricular interventions could help students see potential or real benefits their schoolyards hold for communities.

Previous research suggests that natural elements can enhance student school experience (van Dijk-Wesselius et al., 2018), but we did not find the presence of natural attributes to be a significant predictive factor of students’ perceptions of benefits on its own. In our study, neither the presence of woodlands nor gardens was positively associated with students’ perception of benefits to self and community. The use of natural elements, rather than simple presence, was a more powerful predictor of perceived benefits among students, pointing to the need for school policies and curricular practices that encourage students to interact with the nature-based elements
on schoolyards. This is consistent with many studies supporting the benefits of teacher-led outdoor activities such as establishing a relationship with the landscape (Jansson et al., 2014), making the learning experience more enjoyable (Chawla et al., 2014), enhancing subsequent classroom engagement (Kuo, Browning, & Penner, 2018), and boosting students to understand complex science topics. These findings highlight a need to support efforts such as teacher professional development to encourage the use of schoolyards as learning tools (Akoumianaki-Ioannidou et al., 2016), to support learning (Kuo et al., 2019), to support mental health (Chawla et al., 2014), and as we find, enhance students’ perceived benefits of schoolyards.

Outside of classes, if students are encouraged to observe and play with natural elements, they may reap similar benefits as to when activities are facilitated by the teacher. In our study, looking and playing with plants was positively associated with students perception of benefits to self, which is consistent with previous research finding that sitting in areas surrounded by vegetation (Kelz et al., 2015) and spending time in natural areas (Chawla et al., 2014) supported students’ mental health by reducing psychological stress and enhancing perceived restorativeness. Other perceived benefits such as feeling schoolyards to be attractive or good places to learn could be explained by students developing a connection to natural areas through regular interaction (Jansson et al., 2014). For instance, when students can enter natural areas to see and touch flowering plants and smell the fragrance, they may be more likely to identify the aesthetic or educational value of schoolyards. These findings support calls by others for providing more opportunity and access to natural elements to students. Although students prefer playing in nature-rich areas (Lindemann-Matthies & Köhler, 2019), schoolyards with woods are often fenced citing reasons such as protecting newly planted vegetation or safety concerns (Jansson et al., 2014). Accordingly, installing natural elements on school grounds must be paired with policies friendly
to children accessing nature to reap the associated benefits.

Though not part of our hypotheses, we did find relationships associated with gender and race that may warrant future research. Our finding that boys were less likely than girls to perceive schoolyard benefits to community may be explained by documented differences in schoolyard use between boys and girls. In general, boys are more likely to use spaces for intensive play (e.g. running and playing sports) and thus may spend less time in nature-rich areas (Fjørtoft et al., 2009; van Dijk-Wesselius et al., 2018). As regular contact with nature, including time spent alone or in more contemplative settings, can foster a relationship with nature (Chawla & Derr, 2012; Szczytko, Stevenson, Peterson, & Bondell, 2020), encouraging boys to interact with nature on schoolyards may help them perceive the broader benefits of their schoolyards. We did not find association between race and perceptions of either benefit. The overall lack of relationship between race and perceived benefits is consistent with research suggesting that relationships with and perceptions of nature have stronger roots in experiences rather than demography or culture (Floyd, 1998; Szczytko et al., 2020). However, future research should continue to investigate the experience of children from Black, Hispanic, or other minoritized racial or ethnic identities in schoolyards to promote positive experiences for all children.

As this is one of the few studies to focus explicitly on student perceptions of benefits, future research should continue to explore ways to support students’ positive school experiences through schoolyards. Our study had a relatively small sample size of both students (n = 199) and teachers (n = 14), which may have limited our ability to make inferences from our regression models. The low response rates among teachers and small sample of this study limits generalizability to our study area. Future research should continue to investigate whether our findings hold to broader populations. Further, we did not control the physical structure of the natural areas in our models,
which could impact their use. For example, the use of woodlands may be constrained by dense understories (e.g. dense shrubs and herbaceous cover), and inaccessible areas may cause some negative perceptions of those areas (Lindemann-Matthies & Köhler, 2019). Additionally, we only considered two types of natural elements; there are many other types such as rain gardens and ponds that we did not account for due to the limited school samples. Future research can expand the sample size from more schools to capture different types of natural elements and activities. Though future research is needed to determine whether the relationships found in this study are causal, the correlational results suggest where the school policies and curricular practice may focus to support positive student perceptions of their schoolyards. Similarly, we only asked how often students spend time outdoor for class activities, but we did not specify the type of class activities. Future research can compare the effect of various outdoor class activities (e.g., bird watching, tree identification, planting) on students’ perception of schoolyards benefits.
CHAPTER 5. CONCLUSIONS AND FUTURE RESEARCH

This dissertation presents a novel pathway to expand UGI throughout municipalities (i.e., working through school districts) and simultaneously document green schoolyard benefits to children and broader communities. The overall aim is to provide cross-sector support for UGI, to address environmental justice while also connecting children to nature, and building environmental literacy and engagement. Our findings show that public elementary schoolyards provide equal exposure to UGI, and public school systems are a promising partner to expand GI and urban greening equitably. In addition, we find that students’ positive view of green schoolyards are more influenced by the actual use of GI in schoolyards than greening schoolyards alone. More importantly, teachers can play a considerable role in unlocking the benefits that exist in green schoolyards by promoting children playing in nature-rich areas.

As public school systems are a promising partner to expand GI and urban greening equitably, we recommend that future landscape practitioners focus on increasing the tree canopy cover as well as implementing multi-functional GI. Furthermore, green schoolyards should be designed by or with input from students, teachers, and community members. Our findings provide valuable information for decision making at municipal level. Our results have been shared with WCPSS and broader audience to enhance environmental awareness and incent more people take UGI actions.
REFERENCES


86


Dyment, J. E., & Bell, A. C. (2008). Grounds for movement: Green school grounds as sites for


Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Meza Prado, K. A., …


USFS. (2019). NLCD 2016 USFS Tree Canopy Cover (CONUS) [Data file]. Retrieved from https://www.mrlc.gov/data?f%5B0%5D=category%3Atree_canopy&f%5B1%5D=year%3A2016


Yamaoka, K., Nakagawa, T., & Uno, T. (1978). Application of Akaike’s information criterion (AIC) in the evaluation of linear pharmacokinetic equations. *Journal of Pharmacokinetics and


APPENDICES
Supporting Information

Schoolyards as sources of green equity: understanding spatial and demographic distribution of urban green infrastructure across four public school districts in North Carolina, USA

Zhenzhen Zhang a, Katherine L. Martin a,b*, Kathryn T. Stevenson c, Yuan Yao d

a Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC
b Center for Geospatial Analytics, North Carolina State University, Raleigh, NC
c Department of Parks, Recreation, and Tourism Management, North Carolina State University, Raleigh, NC
d Department of Forest Biomaterials, North Carolina State University, Raleigh, NC

E-mail: katie_martin@ncsu.edu

Table S1. The size of school attendance zone and census tracts in square kilometers (SD).

<table>
<thead>
<tr>
<th>School attendance zone</th>
<th>Census tract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayetteville</td>
<td>10.23 (8.03)</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>17.06 (9.82)</td>
</tr>
<tr>
<td>Charlotte</td>
<td>9.95 (7.24)</td>
</tr>
<tr>
<td>Raleigh</td>
<td>10.26 (6.52)</td>
</tr>
</tbody>
</table>

6.85 (4.57)    6.75 (4.16)    5.14 (4.13)    6.61 (4.73)
<table>
<thead>
<tr>
<th></th>
<th>Fayetteville</th>
<th>Winston-Salem</th>
<th>Charlotte</th>
<th>Raleigh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Producer's accuracy</td>
<td>User's accuracy</td>
<td>Producer's accuracy</td>
<td>User's accuracy</td>
</tr>
<tr>
<td>Bare</td>
<td>97.2%</td>
<td>70.0%</td>
<td>92.1%</td>
<td>70.0%</td>
</tr>
<tr>
<td>Fine vegetation</td>
<td>89.8%</td>
<td>88.0%</td>
<td>80.4%</td>
<td>82.0%</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>60.3%</td>
<td>94.0%</td>
<td>68.9%</td>
<td>84.0%</td>
</tr>
<tr>
<td>Coarse vegetation</td>
<td>88.7%</td>
<td>94.0%</td>
<td>74.2%</td>
<td>92.0%</td>
</tr>
<tr>
<td>Water</td>
<td>97.1%</td>
<td>66.0%</td>
<td>97.4%</td>
<td>74.0%</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>82.4%</td>
<td>80.4%</td>
<td>85.2%</td>
<td>86.4%</td>
</tr>
<tr>
<td>Kappa coefficient</td>
<td>0.78</td>
<td>0.76</td>
<td>0.81</td>
<td>0.83</td>
</tr>
</tbody>
</table>

**Table S2.** Accuracy statistics for Producer’s, User’s, Overall accuracy and Kappa coefficient for land cover across the four school districts.
<table>
<thead>
<tr>
<th>Classified</th>
<th>Fayetteville</th>
<th>Winston-Salem</th>
<th>Charlotte</th>
<th>Raleigh</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>3 0 1 0 0</td>
<td>3 1 2 0 0</td>
<td>11 1 1 0 0</td>
<td>6 0 0 0 0</td>
</tr>
<tr>
<td>G</td>
<td>0 12 0 3 0</td>
<td>0 15 1 0 0</td>
<td>0 19 1 2 0</td>
<td>0 21 1 2 0</td>
</tr>
<tr>
<td>I</td>
<td>0 4 22 1 0</td>
<td>0 0 16 0 1</td>
<td>1 1 35 1 0</td>
<td>0 4 30 1 0</td>
</tr>
<tr>
<td>T</td>
<td>0 1 14 0</td>
<td>0 4 4 25 0</td>
<td>0 7 1 54 0</td>
<td>0 5 2 48 1</td>
</tr>
</tbody>
</table>
| W          | 0 0 0 5      | 0 0 0 0 6    | 0 0 0 0 10 | 0 0 0 0 5  

* B: bare soil, F: fine vegetation, I: impervious surfaces, T: tree, W: water
### Table S4. Land cover in school parcels and school attendance zone, (SD).

<table>
<thead>
<tr>
<th></th>
<th>Bare</th>
<th>Grass/Shrubs</th>
<th>Impervious surface</th>
<th>Tree</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>School</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fayetteville</td>
<td>7.0% (5.7%)</td>
<td>41.8% (15.8%)</td>
<td>31.5% (13.0%)</td>
<td>18.8% (14.5%)</td>
<td>0.9% (1.1%)</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>2.6% (1.7%)</td>
<td>34.0% (10.6%)</td>
<td>35.4% (10.6%)</td>
<td>27.9% (15.3%)</td>
<td>0.1% (0.4%)</td>
</tr>
<tr>
<td>Charlotte</td>
<td>2.9% (3.1%)</td>
<td>34.1% (11.6%)</td>
<td>31.1% (11.4%)</td>
<td>30.6% (15.3%)</td>
<td>1.3% (1.3%)</td>
</tr>
<tr>
<td>Raleigh</td>
<td>3.9 (2.7%)</td>
<td>30.1 (9.7%)</td>
<td>30.6 (9.8%)</td>
<td>35.0 (14.5%)</td>
<td>0.4 (0.9%)</td>
</tr>
<tr>
<td>All four cities</td>
<td>3.8% (3.7%)</td>
<td>33.9% (12.2%)</td>
<td>31.5% (11.0%)</td>
<td>29.9% (15.8%)</td>
<td>0.9% (1.2%)</td>
</tr>
<tr>
<td><strong>School attendance zone</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fayetteville</td>
<td>2.0% (1.0%)</td>
<td>26.1% (5.8%)</td>
<td>21.0% (7.4%)</td>
<td>48.9% (7.3%)</td>
<td>2.0% (1.1%)</td>
</tr>
<tr>
<td>Winston-Salem</td>
<td>2.1% (1.5%)</td>
<td>24.1% (4.8%)</td>
<td>23.5% (12.1%)</td>
<td>49.5% (9.4%)</td>
<td>0.7% (0.5%)</td>
</tr>
<tr>
<td>Charlotte</td>
<td>2.2% (1.3%)</td>
<td>23.8% (5.0%)</td>
<td>23.8% (9.5%)</td>
<td>47.6% (9.2%)</td>
<td>2.7% (2.2%)</td>
</tr>
<tr>
<td>Raleigh</td>
<td>3.2% (2.3%)</td>
<td>22.2% (5.5%)</td>
<td>21.1% (7.4%)</td>
<td>51.8% (9.5%)</td>
<td>1.7% (1.3%)</td>
</tr>
<tr>
<td>All four cities</td>
<td>2.6% (1.8%)</td>
<td>23.6% (5.5%)</td>
<td>22.3% (8.9%)</td>
<td>49.6% (9.2%)</td>
<td>1.9% (1.7%)</td>
</tr>
</tbody>
</table>
Supporting Information

Exploring geographical, curricular, and demographic factors of nature use by children in urban schoolyards in Raleigh, NC, USA

Zhenzhen Zhang a*, Kathryn T. Stevenson b, Katherine L. Martin a, c
a Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC
b Department of Parks, Recreation, and Tourism Management, North Carolina State University, Raleigh, NC
c Center for Geospatial Analytics, North Carolina State University, Raleigh, NC

*E-mail: zzhang59@ncsu.edu
S1. Survey for students; Online version is available from bit.ly/greenschool-student.

Q1 Does your school have places that look like any of these pictures? Click on all the pictures that look similar to your schoolyard.

☐ An area with shrubs, tall grasses and/or flowers. Usually this often in a sunken or low area. (1)

☐ Raised beds for growing flowers, herbs, vegetables, or fruits. (2)

☐ A garden with mostly flowers. (4)

☐ A natural area near buildings, with grass and trees (3)

☐ Woods or a forest (5)

☐ A playground (6)

☐ An athletic field (8)

☐ An open space with tall grasses (not an athletic field) (10)

☐ A pond (7)
Q3 How often do you do each of these activities in your schoolyard?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never (1)</th>
<th>Once or twice a year (2)</th>
<th>About once a month (3)</th>
<th>About once a week (4)</th>
<th>Several times a week or more (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spend time learning with my teacher</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend time outside for recess</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Play sports (e.g. baseball, soccer, run club etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing games other than sports (e.g., chase, play games)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look at or play with plants (e.g., pick flowers, lay in the grass)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look at or play with insects or small animals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend time in a garden</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explore the woods or shrubland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q7 Do you think the following places would be a good place to learn?
<table>
<thead>
<tr>
<th>An area with shrubs, tall grasses and/or flowers. Usually this often in a sunken or low area. (1)</th>
<th>No way 👎👎 (1)</th>
<th>Probably not 👎 (2)</th>
<th>Maybe 💡 (3)</th>
<th>Probably 👍 (4)</th>
<th>Definitely 👍👍 (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raised beds for growing flowers, herbs, vegetables, or fruits. (2)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>A garden with mostly flowers. (4)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>
Q7 Do you think the following places would be a good place to learn? (Continued)

<table>
<thead>
<tr>
<th>Place</th>
<th>No way</th>
<th>Probably not</th>
<th>Maybe</th>
<th>Probably</th>
<th>Definitely</th>
</tr>
</thead>
<tbody>
<tr>
<td>A natural area near buildings, with grass and trees (3)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Woods where you can explore or play (5)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>A playground (6)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>An open space with tall grasses (not an athletic field) (8)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>An athletic field (9)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>A pond (7)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Q9 What is your gender?

- ☐ Girl (1)
- ☐ Boy (2)
- ☐ Something else (3)
Q10 What is your race or ethnicity? Please check all that apply.

- White or Caucasian (1)
- African-American (2)
- Hispanic (3)
- Asian (4)
- Pacific Islander (5)
- Native American (6)
- Something else (7)
S2. Survey for students; Online version is available from bit.ly/greenschool-student.

Q1 Does your school have places that look like any of these pictures? Click on all the pictures that look similar to your schoolyard

☐ An area with shrubs, tall grasses and/or flowers. Usually this often in a sunken or low area. (1)

☐ Raised beds for growing flowers, herbs, vegetables, or fruits. (2)

☐ A garden with mostly flowers. (4)

☐ A natural area near buildings, with grass and trees. (3)

☐ Wooded area or forest. (5)

☐ A playground (6)

☐ An open space with tall grasses (not an athletic field). (7)

☐ An athletic field (9)

☐ A pond (8)

Q9 Have you ever attended a professional development workshop related to environmental education

☐ Yes (1)

☐ No (2)
Q10 Do you take your students outdoor during class time (i.e., not recess)?

- Yes   (1)
- No    (2)

If Q10, do you take your students outdoor during class time (i.e., not recess)? = Yes

Q11 How often do you take students outdoor?

- Daily   (1)
- 2-3 times a week   (2)
- Weekly   (3)
- 1-2 times a month   (4)
- Monthly   (5)
- 1-2 times a semester   (6)
- 1-2 times a year   (7)
- Once a year   (8)
Table S3. Land cover in school properties.

<table>
<thead>
<tr>
<th>School code</th>
<th>Bare soil</th>
<th>Lawn/grass</th>
<th>Impervious surfaces</th>
<th>Tree canopy</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.1%</td>
<td>25.7%</td>
<td>30.3%</td>
<td>40.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2</td>
<td>4.3%</td>
<td>37.3%</td>
<td>24.9%</td>
<td>33.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3</td>
<td>10.3%</td>
<td>21.3%</td>
<td>36.8%</td>
<td>30.0%</td>
<td>1.6%</td>
</tr>
<tr>
<td>4</td>
<td>1.1%</td>
<td>20.9%</td>
<td>53.0%</td>
<td>24.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>5</td>
<td>2.6%</td>
<td>7.9%</td>
<td>44.8%</td>
<td>44.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td>6</td>
<td>14.1%</td>
<td>19.7%</td>
<td>60.2%</td>
<td>6.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>7</td>
<td>4.3%</td>
<td>25.8%</td>
<td>37.9%</td>
<td>31.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>8</td>
<td>0.2%</td>
<td>28.0%</td>
<td>25.0%</td>
<td>47.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>9</td>
<td>0.1%</td>
<td>26.9%</td>
<td>50.0%</td>
<td>22.9%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>
Supporting Information

Use of nature-based school grounds can enhance students’ perceptions of schoolyard benefits

Zhenzhen Zhang a, Kathryn T. Stevenson b*, Katherine L. Martin a, c

a Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC
b Department of Parks, Recreation, and Tourism Management, North Carolina State University, Raleigh, NC
c Center for Geospatial Analytics, North Carolina State University, Raleigh, NC

*E-mail: ktate@ncsu.edu
Table S1. Mann-Whitney U tests for responses between 3rd grade and higher grade students

<table>
<thead>
<tr>
<th>How much do you agree or disagree with the following statement? My schoolyard is…</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A good place to play</td>
<td>0.10</td>
</tr>
<tr>
<td>A good place to learn</td>
<td>0.14</td>
</tr>
<tr>
<td>Helping me feel energized</td>
<td>0.37</td>
</tr>
<tr>
<td>Helping me feel calm</td>
<td>0.94</td>
</tr>
<tr>
<td>Attractive</td>
<td>0.19</td>
</tr>
<tr>
<td>A good place to grow food</td>
<td>0.61</td>
</tr>
<tr>
<td>Making air cleaner</td>
<td>0.45</td>
</tr>
<tr>
<td>Home for animals</td>
<td>0.29</td>
</tr>
<tr>
<td>Helping reduce flooding</td>
<td>0.85</td>
</tr>
<tr>
<td>Making water cleaner</td>
<td>0.92</td>
</tr>
</tbody>
</table>

S2. Survey for students; Online version is available from bit.ly/greenschool-student

Q1 Does your school have places that look like any of these pictures? Click on all the pictures that look similar to your schoolyard.

- An area with shrubs, tall grasses and/or flowers. Usually this often in a sunken or low area. (1)
- Raised beds for growing flowers, herbs, vegetables, or fruits. (2)
- A garden with mostly flowers. (4)
- A natural area near buildings, with grass and trees (3)
- Woods or a forest (5)
- A playground (6)
- An athletic field (8)
- An open space with tall grasses (not an athletic field) (10)
- A pond (7)
Q3 How often do you do each of these activities in your schoolyard?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never (1)</th>
<th>Once or twice a year (2)</th>
<th>About once a month (3)</th>
<th>About once a week (4)</th>
<th>Several times a week or more (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spend time learning with my teacher (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend time outside for recess (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Play sports (e.g. baseball, soccer, run club etc.) (3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing games other than sports (e.g., chase, play games) (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look at or play with plants (e.g., pick flowers, lay in the grass) (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Look at or play with insects or small animals (6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spend time in a garden (7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explore the woods or shrubland (8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Q4 How much do you agree with the following statement? My schoolyard ...

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>... is attractive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... is a good place to play</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... helps me feel energized</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... helps me feel calm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... is a good home for animals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... helps make the air less polluted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... helps make the water cleaner</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... helps reduce flooding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... is a good place to learn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... provides space to grow food</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table S3. Variance inflation factors (VIF) analysis for examining collinearity.

<table>
<thead>
<tr>
<th>Variables</th>
<th>VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodland</td>
<td>1.21</td>
</tr>
<tr>
<td>Garden</td>
<td>1.10</td>
</tr>
<tr>
<td>Class activities</td>
<td>1.13</td>
</tr>
<tr>
<td>Look and play with plants</td>
<td>1.20</td>
</tr>
<tr>
<td>Look and play with animals</td>
<td>1.23</td>
</tr>
</tbody>
</table>