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GREEN INFRASTRUCTURE IN SCHOOLS: CREATING A NETWORK FOR STORMWATER MANAGEMENT AND STUDENT ENGAGEMENT AND WELL-BEING

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Abstract

The two goals of this project were (1) to understand the spatial distribution of green infrastructure (GI) in schoolyards and associated benefits across school districts and communities that these school districts serve in North Carolina, (2) to understand how the placing GI in schoolyards, which we refer to as green schoolyards, improve children's access to nature and its benefits through a case study in the City of Raleigh. This proposal addresses Focus Area 3: Community Development and Stormwater/Watershed Management through engaging children and teachers in public schools to better understand the existing capacity of GI on school grounds and potential benefits to children and communities. Specifically, we addressed three research questions: *R1) Do schools enhance or mitigate inequities in children's exposure to GI?* R2) *Does greening schoolyards improve students' perceptions of the benefits of schoolyards?* and *R3) What factors predict children's play in nature-rich areas as compared to traditional outdoor places in schoolyards.* For R1, we focused on tree canopy and total greenness across four largest school districts in North Carolina, and for R2 and R3, we focused on nature-based elements in individual schoolyards, the use of schoolyards by students and teachers and the perception of students.

The results of this project highlight that (1) public elementary schoolyards provide equitable exposure to tree canopy cover and total greenness, and public school systems are a promising partner to expand GI and urban greening equitably; (2) students' positive view of schoolyards are more influenced by nature-based activities and teacher-led activities than greening schoolyards alone; (3) teachers can play a considerable role in unlocking the benefits that exist in green schoolyards by promoting children playing in nature-rich areas. Our findings can serve as a decision support for better GI planning, design for stormwater management and other co-benefits in partnership with schools.

1. Introduction

Green infrastructure (GI) such as urban green spaces, urban forests, woodlands (Benedict & McMahon., 2002) provide a range of ecosystem services for urban environments (Seiwert & Rößler, 2020). For instance, regulating stormwater runoff is one of ecosystem service that GI can provide. GI represents a promising alternative to traditional stormwater management as it offers more cost-effective than replacing old drainage pipes (Kessler, 2011). Further, GI provide benefits beyond stormwater management such as air pollution removal, urban heat mitigation, wildlife habitat creation, and atheistic and educational value (Iojă, Grădinaru, Onose, Vânău, & Tudor, 2014; Krasny, Russ, Tidball, & Elmqvist, 2014; Lin, Philpott, & Jha, 2015). However, there are several barriers asscioated with GI expansion. For example, the difficulty in coordinating across multiple departments in a municipal level, lacking financial or regulatory incentives, and stakeholder resistance to change or lack of awareness (Hopkins, Grimm, & York, 2018; UNC Environmental Finance Center, 2018; Venkataramanan et al., 2020)

Public school systems as municipal units, present important stakeholders that have the capacity to adopt GI in schoolyards and expand GI benefits to children and communities. First, schoolyards public school properties include a significant amount of impervious surface area (e.g., 32% of school property is impervious surface in the City of Raleigh [UNC Environmental Finance Center, 2018]), representing an opportunity for GI implementation. Each school district, as a single stakeholder, has the potential to make big impact for mitigating stormwater issue by creating GI network without having to coordinate heavily across sectors. Second, schools have an opportunity to provide GI benefits to a population that may receive long-term benefits from them. As students spent a significant portion time at schools (Ozdemir & Yilmaz, 2008), placing GI on school grounds in ways that promote green schoolyards has the potential to benefit both students and staff (Kerlin, Santos, & Bennett, 2015). These co-benefits associated with GI can vary from improving physical and mental health (Chawla, Keena, Pevec, & Stanley, 2014), enhancing academic performance of students (Kuo, Browning, & Penner, 2018), to providing wide range of ecosystem services benefiting broader communities (Bates, Bohnert, & Gerstein, 2018; Calderón-Contreras & Quiroz-Rosas, 2017; Iojă et al., 2014).

One key step in building cross-sector support for GI in schools is understanding its current implementation as well as current and potential use by preferences of teachers and students. Previous studies have examined the effect of GI on stormwater control on a campus level (Damodaram et al., 2010); other studies also document the benefits of green schoolyards on student learning and well-being (Li & Sullivan, 2016; Parmer, Salisbury-Glennon, Shannon, & Struempler, 2009; Plaka & Skanavis, 2016). However, there is limited study that examines these benefits together with the goal of building cross-sector support for GI around potential dual benefits. By coupling these potential benefits within a single study, results could shed light on ways to implement GI that optimizes benefits for both municipalities (i.e., stormwater management) and students (i.e., learning and well-being).

The goal of this project is to understand to understand the range of GI that exists on school grounds as well as highlight opportunities for use by schools to benefit students. Specifically, we addressed the following research questions: 1) *Do schools enhance or mitigate inequities in children's exposure to GI?* 2: *Does greening schoolyards improve students' perceptions of the benefits of schoolyards?* and 3: *What factors affect children play in nature-rich areas rather than traditional outdoor places in schoolyards.* This project provides an understanding of the distribution of GI across four school districts and in multiple demographic contexts in North Carolina. Additionally, by identifying the preferred environment, usage, activities teachers and students assigned to green infrastructure, we provide recommendations for how schools initiating GI project may better design for stormwater management as well as outdoor play and education. Highlighted co-benefits may also facilitate cross-sector support from parents and other third parties, which can assist project development and long-term maintenance.

2. Methods

2.1 Research Question 1

We selected four county-wide school districts across North Carolina: Cumberland, Forsyth, Mecklenburg and Wake (Figure 1). First, we used color infrared (CIR) imagery to classify land cover of schoolyards and neighborhoods into five categories: bare, grass/lawn, impervious surface (roads and buildings), tree canopy and water. We focused on tree canopy cover and total greenness separately given the particular benefits provided by trees. Then, to determine if land cover demographic patterns were different in schoolyards compared to surrounding areas, we compared the tree canopy cover and overall greenness in neighborhoods (represented by school attendance zones) to the socioeconomic and race/ethnicity demographics of the neighborhoods. To be specific, for schools, we collected demographic information including race/ethnicity and the percent of students eligible for free and reduced lunch (FRL) as an indicator of socioeconomic status (Nicholson, Slater, Chriqui, & Chaloupka, 2014). For the neighborhoods, we used the Social Vulnerability Index (SVI) (Centers for Disease Control and Prevention (CDC), 2016) to represent the socioeconomic and race/ethnicity demographics of the neighborhoods.

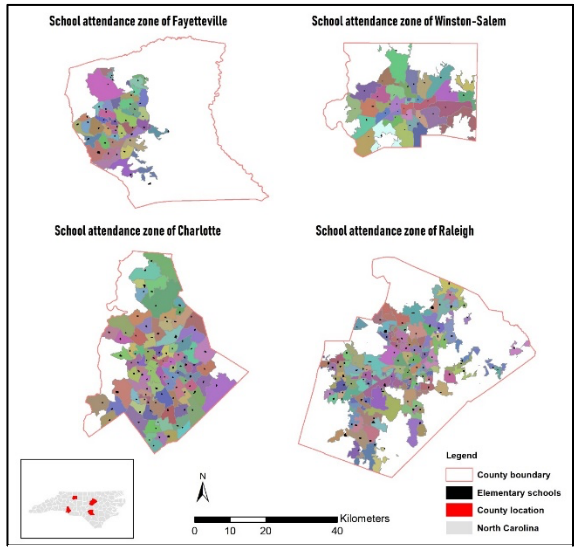

Figure. 1. Elementary schools and neighborhoods (colored areas) within urban

For statistical analyses, we first used Spearman's correlation to analyze the bivariate relationship between GI, socioeconomic status, and race/ethnicity for each city and four cities as a whole. Then we used ordinary least squares regression (OLS) and spatial lag model (SLAG) to examine relationships between tree canopy and total greenness (as responses variables) and FRL rate and the percentage of students identifying as peoples of color (independent variables) in schools, and two SVI themes (independent variables) in the neighborhoods.

2.2 Research Questions 2 and 3

To better understand current and potential use of GI to benefit student learning and well-being, we narrowed the spatial scale at school level, focusing on students and teachers within Wake County Public elementary schools within the Raleigh city limits. We chose 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).

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 Wake County Public School

System (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). 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 1. In the survey, we asked students to self-report their gender, race, and grade level, as well as the name of their teacher. Beyond these demographic questions, all responses were anonymous.

Table 1. Summary of students and teacher participants for the survey

	Students (199 students in 9 schools)	Teachers (14 teachers in 9 schools)
Grade		
3th	11.6	7.1
4th	41.2	57.1
5th	39.2	28.6
6th	8.0	7.1
Gender		
Girl/Female	59.3	92.9
Boy/Male	40.7	7.1
Race/Ethnicity		
White	35.7	92.9
Black	20.6	7.1
Hispanic	13.6	-
Asian	3.5	-
Pacific islander	1.0	-
Native American	3.0	-
Two or more	8.0	-
Other	14.6	-

2.2.1 Research Question 2 survey questions and data analysis

To understand students' perception of schoolyards, we measured several benefits to self and benefits to community. 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 (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). 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", and 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 conducted principal axis factor analysis (PAF) and linear regression models to examine students' perception of schoolyards' benefits to self and community as a function of the nature-based attributes (i.e. woodlands and gardens), nature-based activities by students, and use lead by teachers. Then, we used linear regression models to examine the individual benefits (i.e., each item) as a function of nature-based attributes and use by students and teachers to capture nuanced differences. We also controlled for students' demographic background and a random effect for teachers.

2.2.2 Research question 3 survey questions and data analysis

We asked a 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 2). 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). 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 same1-5 frequency scale as on the student instrument.

Figure 2. Four GI types in schoolyards

To understand whether students' awareness of nature-rich green spaces (i.e. garden and woodland), we used logistic regression to model the students' awareness as a function of the frequency of teachers taking students outdoors and teachers' professional development background. In this model, we included a random effect for teachers because students from the same classroom may have similar awareness and behaviors on school grounds. In addition, we also controlled ground truth and students' demographic background (e.g., gender and race/ethnicity).

Then we used multiple linear regression, ordinary least squares regression (OLS) and spatial lag model (SLAG). We modeled 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 and the ground truth, and included a random effect for teacher as well.

3. Results

3.1 Objective 1

Across all cities, the average tree canopy cover in schoolyards was lower than in the neighborhoods (Table 1). In schoolyards, tree canopy cover (± SD) was highest in Raleigh (35 ± 14%) and Charlotte (31 ± 15%), followed by Winston-Salem (28 ± 15%) and Fayetteville (19 ± 14%). In neighborhoods, Raleigh had the highest tree canopy cover at 52± 9%, followed by Winston-Salem 50 ± 9%, Fayetteville 49 ± 7% and Charlotte 48 ± 9%. In the majority of schoolyards, mean total greenness exceeded 60% in all school districts, ranging between 61± 15.9% in Fayetteville to 65 ± 11% in Raleigh (Table. 1). In neighborhoods, greenness of the four cities was higher than in schoolyards, all above 70%. Within total greenness, grass/lawn (greenness – tree canopy) was a significant land cover type and generally more extensive in schoolyards than in neighborhoods. 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%).

Table 2. The average of demographics statistics (SD) at the school and neighborhood level across the urban portion of school districts and the rate of tree canopy cover and total greenness (SD). Neighborhoods refer to school attendance zones.

	FRL [a]	Peoples of color [b]	SVI Socioeconomic status [c]	SVI Race/ethnicity /language [d]	Tree in schools	Trees in neighborhoods	Greenness in schools	Greenness in neighborhoods
Fayetteville	85.5% (22.1%)	76.6% (14.4%)	2.26 (0.58)	1.30 (0.14)	18.8% (14.5%)	48.9% (7.3%)	60.6% (15.9%)	75.0% (7.7%)
Winston-Salem	74.0% (33.4%)	68.4% (28.6%)	2.05 (1.04)	1.20 (0.46)	27.9% (15.3%)	49.5% (9.4%)	61.9% (11.4%)	73.6% (12.1%)
Charlotte	69.3% (37.9%)	76.4% (25.9%)	1.79 (1.09)	1.34 (0.44)	30.6% (15.3%)	47.6% (9.2%)	65.0% (12.4%)	71.3% (9.2%)
Raleigh	37.8% (20.4%)	56.3% (20.4%)	1.17 (0.72)	1.10 (0.37)	35.0% (14.5%)	51.8% (9.5%)	65.1% (11.0%)	74.0% (7.5%)
Continental US	-	-	1.99 (0.98)	0.98 (0.54)	29.9% (15.8%)	49.6% (9.2%)	63.8% (12.3%)	73.2% (8.9%)

[a] FRL is the average free and reduced lunch population of schools, presenting the socioeconomic status of students who attend schools (U.S. Department of Education, 2019).

[b] 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 Socioeconomic status theme presents the social economic status of neighborhoods (school attendance zones).

[d] SVI Race/ethnicity theme presents the race/ethnicity status of neighborhoods.

From Spearman's correlation, at the school level, we found very little relationship between land cover and school demographics (Table 3). The only relationship was found in Raleigh, a positive relationship between tree canopy cover and FRL ($p < 0.05$). The remaining correlations between tree canopy cover or total greenness and FRL were not statistically significant. Likewise, we did not find any statistically significant correlations between tree canopy cover or total greenness and the percentage of peoples of color in schools in any of the cities or when the cities were combined. For Neighborhoods, we found significant negative correlations between socioeconomic vulnerability and both tree canopy cover and total greenness in Winston-Salem ($p < 0.01$) and in Charlotte ($p < 0.01$). In Raleigh, we identified a negative relationship between socioeconomic vulnerability and tree canopy cover ($p < 0.05$), but no significant relationship with total greenness. There was no relationship between tree canopy and socioeconomic vulnerability in Fayetteville. For race/ethnicity, the four cities on average, there was also less overall greenness and canopy cover in neighborhoods with higher proportions of peoples of color ($p < 0.001$). 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 greenness in Winston-Salem ($p < 0.01$) and Charlotte ($p < 0.05$), and weaker negative relationships in Raleigh and Fayetteville ($p < 0.1$).

Similarly, from regression models, at school level, we did not find any significant relationships between tree canopy cover, FRL and peoples of color. We also did not find any significant relationships between total greenness, FRL and peoples of color in any city or when the cities were combined (Table 4). In comparison, for neighborhoods, we found a strong negative relationship between socioeconomic vulnerability and both tree canopy cover and total greenness ($p < 0.01$) using OLS. In Charlotte, SVI for race/ethnicity/language status was negatively associated with total greenness using OLS ($p < 0.05$). In Raleigh, race/ethnicity/language status was negatively associated to tree canopy cover and total greenness ($p < 0.05$). In the four cities as a whole, economic vulnerability was negatively associated with tree canopy ($p < 0.01$) and total greenness ($p < 0.05$) using OLS. Race/ethnicity/language status had a negative association with total greenness ($p < 0.05$) and had a weaker association with tree canopy ($p < 0.1$) (Table 5).

Table 3. Spearman's correlation results of tree, total greenness and school-level measures of socioeconomic status (FRL) and race/ethnicity (students identifying as peoples of color).

	FRL		**Peoples of color rate**		**SVI Socioeconomic status**		**SVI Race/ethnicity/language status**	
	Tree	Total greenness	Tree	Total greenness	Tree	Total greenness	Tree	Total greenness
Fayetteville	0.25	0.06	0.11	0.11	-0.06	-0.02	-0.21	**-0.26 '**
Winston-Salem	-0.05	-0.24	-0.05	-0.24	**-0.53 *****	**-0.46 ****	**-0.50 ****	**-0.52 ****
Charlotte	0.06	-0.04	0.01	-0.02	**-0.28 ****	**-0.41 *****	-0.15	**-0.21 ***
Raleigh	**0.25 ***	0.10	0.12	0.08	**-0.22 ***	-0.004	**-0.30 ****	**-0.18 '**
Average	-0.08	-0.07	-0.04	-0.02	**-0.27 *****	**-0.21 *****	**-0.26 *****	**-0.23 *****

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

Table 4. OLS and SLAG for trees, total greenness and demographics in schools

		Fayetteville		Winston-Salem		Charlotte		Raleigh		All four cities	
		OLS	SLAG	OLS	SLAG	OLS	SLAG	OLS	SLAG	OLS	SLAG
Tree	FRL	0.13	-	-0.19	-	0.10	-	0.16	0.13	-0.08	-0.02
	Peoples of color	-0.008	-	0.19	-	-0.12	-	-0.06	-0.07	0.06	-0.001
	AIC	-37.4		-27.1	-	-77.8		-95.5	-102.2	-224.1	-242.8
Total greenness	FRL	0.002	-0.02	-0.16	-	0.07	-	0.01	0.02	-0.03	-0.02
	Peoples of color	-0.01	-0.06	0.07	-	-0.1	-	0.02	0.01	0.01	0.003
	AIC	-28.5	-44.0	-51.2	-	-113.3	-	-153.2	-155.1	-352.5	-364.7

Note: ' $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; "-": no spatial autocorrelation was identified.

Table 5. OLS and SLAG models for trees, total greenness and demographics in neighborhoods

		Fayetteville		Winston-Salem		Charlotte		Raleigh		All four cities	
		OLS	SLAG	OLS	SLAG	OLS	SLAG	OLS	SLAG	OLS	SLAG
Tree	SVI Socioeconomic status	-0.007	-0.01	-0.04	-0.03	**-0.03 ****	**-0.02 '**	-0.004	0.004	**-0.02 ***	-0.01
	SVI Race/ethnicity/ language status	0.02	0.04	-0.01	-0.02	0.04	0.01	**-0.06 ***	**-0.05 ***	-0.03	**-0.02 '**
	AIC	-94.1	-94.9	-71.6	-73.6	-177.5	-194.4	-223.9	-249.8	-533.8	-582.4
Total greenness	SVI Socioeconomic status	-0.004	0.001	-0.01	0.01	**-0.05 *****	**-0.02 ***	0.01	0.01	**-0.02 ***	-0.003
	SVI Race/ethnicity/ language status	-0.05	0.004	-0.10	-0.1	**-0.06 ***	0.01	**-0.06 ***	**-0.05 ***	-0.02	**-0.03 ***
	AIC	-89.7	-96.6	-52.3	-66.4	-187.3	-202.6	-226.1	-239.2	-619.4	-541.7

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

3.2 Research Question 2

The factor analysis identified two factors fitting in the expected two-theme structure that we defined for benefits (Table 6). All items' loadings were larger than 0.4, above the acceptable level in social science studies, indicating the two-factors structure, benefits to self and benefits to community, fit our data well (Costello & Osborne, 2005). In general, self-report results showed that students were more likely to identify benefits to self than benefits to community (Table 6). 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).

From regression models, when examining predictors 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 predictors of benefits to self, but found no significant predictors of perceived benefits to community associated with schoolyard attributes or use (Table 7). We found that boys perceived fewer benefits to community than girls did ($p < 0.05$). Individual regressions revealed more nuanced relationships. We found that nature-based attributes (woodlands and gardens), were positively associated with students' perceptions of schoolyards being a good place to learn ($p < 0.05$; Table 8). Gardens also predicted students' perceptions of schoolyards as a place of food production ($p < 0.05$; Table 9). However, the relationship between nature-based attributes and perceptions of other benefits was limited, as we found no other relationships. We found that the teacher-led activities outside were significantly and positively related to students' perception of schoolyards as attractive, a good place to play, and a good place to learn. In addition, we found weak relationships ($0.1 < p < 0.13$) between class activities and helping students feel energized, a perception of schoolyards as a home for animals, and schoolyards helping reduce flooding. We also found that playing with plants was positively associated with students feeling calm ($p < 0.05$) and weakly associated with the perception of schoolyards as attractive and a good place to learn ($p < 0.1$). Similarly, playing with animals was associated with the perception of schoolyards as attractive ($p < 0.05$) and weakly with the perceptions of schoolyards as a home for animals ($p < 0.1$). We found that boys were less likely than girls to perceive the schoolyards' benefits to wildlife and water quality. Black students reported less attractiveness of schoolyards than students identifying as White or Caucasian.

Table 6. Students' perceived benefits summary statistics with a broader benefits category from the factor analysis (n = 199)

			Standardized loadings (Pattern Matrix)	
Benefits category, with specific benefits	Mean	SD	Factor A	Factor B
A. Schoolyards' benefits to self (Cronbach's α = 0.67)	3.60	1.16		
A good place to play	3.95	1.03	0.643	-0.223
A good place to learn	3.83	1.18	0.433	0.390
Helping me feel energized	3.61	1.17	0.581	0.137
Helping me feel calm	3.36	1.17	0.400	0.184
Attractive	3.24	1.09	0.722	0.060
B. Schoolyard's benefits to communities (Cronbach's α = 0.75)	3.10	1.21		
A good place to grow food	3.47	1.22	0.173	0.408
Making air cleaner	3.30	1.11	-0.097	0.743
Home for animals	3.20	1.41	0.039	0.851
Helping reduce flooding	2.76	1.02	-0.021	0.720
Making water cleaner	2.75	1.05	0.052	0.785

Table 7. Regression models predicting individual benefits to self, based on schoolyards' attributes and use, controlling students' demographic (n = 199), including a nested random effect for teachers.

	Attractive			A good place to play			A good place to learn			Helping me feel calm			Helping me feel energized		
Variable	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*
Nature-based attributes															
Woodland	0.16	0.19	0.07	-0.05	0.83	-0.02	**0.56 ***	0.26	0.23	-0.29	0.23	-0.12	0.28	0.26	0.12
Gardens	0.15	0.18	0.07	0.09	0.24	0.04	**0.54 ***	0.26	0.22	-0.10	0.23	-0.04	0.18	0.26	0.08
Activities															
Class activities	**0.20 ***	0.06	0.25	**0.15 ***	0.06	0.19	**0.18 ****	0.07	0.22	0.08	0.07	0.09	**0.12 (p = 0.12)**	0.07	0.13
Play with plants	**0.10 '**	0.05	0.14	0.05	0.05	0.06	**0.11 '**	0.06	0.14	**0.14 ***	0.06	0.17	0.05	0.06	0.06
Play with animals	**0.16 ***	0.06	0.18	0.05	0.06	0.07	-0.03	0.06	-0.04	0.07	0.07	0.08	0.04	0.07	0.05
Demographics															
Gender boy	-0.23	0.15	-0.11	-0.21	0.15	-0.10	-0.07	0.16	-0.03	0.06	0.17	0.03	-0.14	0.17	-0.07
Black	**-0.52 '**	0.21	-0.19	-0.02	0.15	-0.01	-0.01	0.23	-0.01	0.31	0.24	0.11	-0.18	0.25	-0.06
Hispanic	0.12	0.24	0.04	0.07	0.24	0.02	-0.26	0.26	-0.08	-0.01	0.27	-0.01	0.09	0.28	0.03
Other	0.06	0.18	0.03	-0.12	0.18	-0.05	0.15	0.19	0.06	0.23	0.20	0.09	-0.04	0.20	-0.02
R^2	0.21			0.13			0.22			0.11			0.10		

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

Table 8. Regression models predicting individual benefits to community, based on schoolyards' attributes and use, controlling students' demographic (n = 199), including a nested random effect for teachers.

	A good place to grow food			Home for animals			Help reduce flooding			Making air more healthier			Making water more healthier		
Variable	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*	*B*	SE	*β*
Nature-based attributes															
Woodland	0.05	0.32	0.02	0.60	0.42	0.20	0.12	0.26	0.20	0.22	0.21	0.10	0.09	0.30	0.04
Gardens	**1.02 ****	0.34	0.4	0.22	0.45	0.08	0.28	0.27	0.08	0.09	0.21	0.04	0.32	0.32	0.15
Activities															
Class activities	0.01	0.07	0.01	**0.13 (p = 0.12)**	0.07	0.12	**0.10 (p = 0.11)**	0.06	0.12	0.06	0.07	0.07	0.05	0.06	0.06
Play with plants	0.02	0.06	0.03	0.05	0.07	0.06	0.002	0.05	0.06	0.08	0.06	0.11	0.03	0.05	0.05
Play with animals	0.08	0.07	0.09	**0.13 '**	0.07	0.12	0.01	0.07	0.12	0.04	0.07	0.05	0.03	0.06	0.03
Demographics															
Gender boy	-0.14	0.16	-0.06	**-0.40 ***	0.18	-0.14	-0.05	0.15	-0.14	-0.25	0.16	-0.11	**-0.30 ***	0.15	-0.14
Black	-0.18	0.24	-0.06	-0.21	0.27	-0.06	0.10	0.22	-0.06	-0.11	0.23	-0.04	0.11	0.22	0.04
Hispanic	-0.09	0.26	-0.03	0.07	0.30	0.02	-0.06	0.24	0.02	0.10	0.26	0.03	0.13	0.24	0.04
Other	-0.15	0.19	-0.06	0.12	0.22	0.04	0.01	0.18	0.04	0.13	0.19	0.05	0.19	0.18	0.08
R^2	0.29			0.29			0.13			0.09			0.20		

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

3.3 Research question 3

Among the 9 schools that participated in our study (n=9), 3 schools had woodlands (33.3%) and 6 schools had gardens (66.7%). In comparison, all schools (100%) had athletic fields and 8 schools (89%) had playgrounds (Table 9). Students were most aware of playground and athletic fields with students correctly identifying their presence over 70% of the time. In schools which had 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.

Self-report results showed that students participated in nature-based activities much less frequently than traditional outdoor activities like sports and recess. 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 (Figure 3.).

From regression models, 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. However, only presence of a woodland was a significant predictor of student awareness ($p = 0.051$), as neither teacher attribute was significant. As predicted, teachers' EE workshop experience was not a significant predictor of student awareness of traditional outdoor spaces. However, students were less aware of playgrounds when their teachers took them outdoors frequently ($p < 0.05$) (Table 10). For student use of nature-rich areas, though neither teacher attribute predictor was related to students spending time in gardens, we found that teachers who had EE professional development was positively related to students exploring woodlands ($p = 0.02$). Student responses that woodlands were "a good place to learn" were positively related to exploring woodlands ($p = 0.08$). In contrast, we did not find either teacher attribute to be related to the traditional activities. We found that boys were more likely than girls to report that they played sports (p = 0.01). Black students reported playing sports more frequently than rest of other races. Students identifying as a race other than White, Black or Hispanic reported higher frequency in exploring woodlands, and those identifying as Hispanic students reported less frequent recess than white students (p = 0.05).

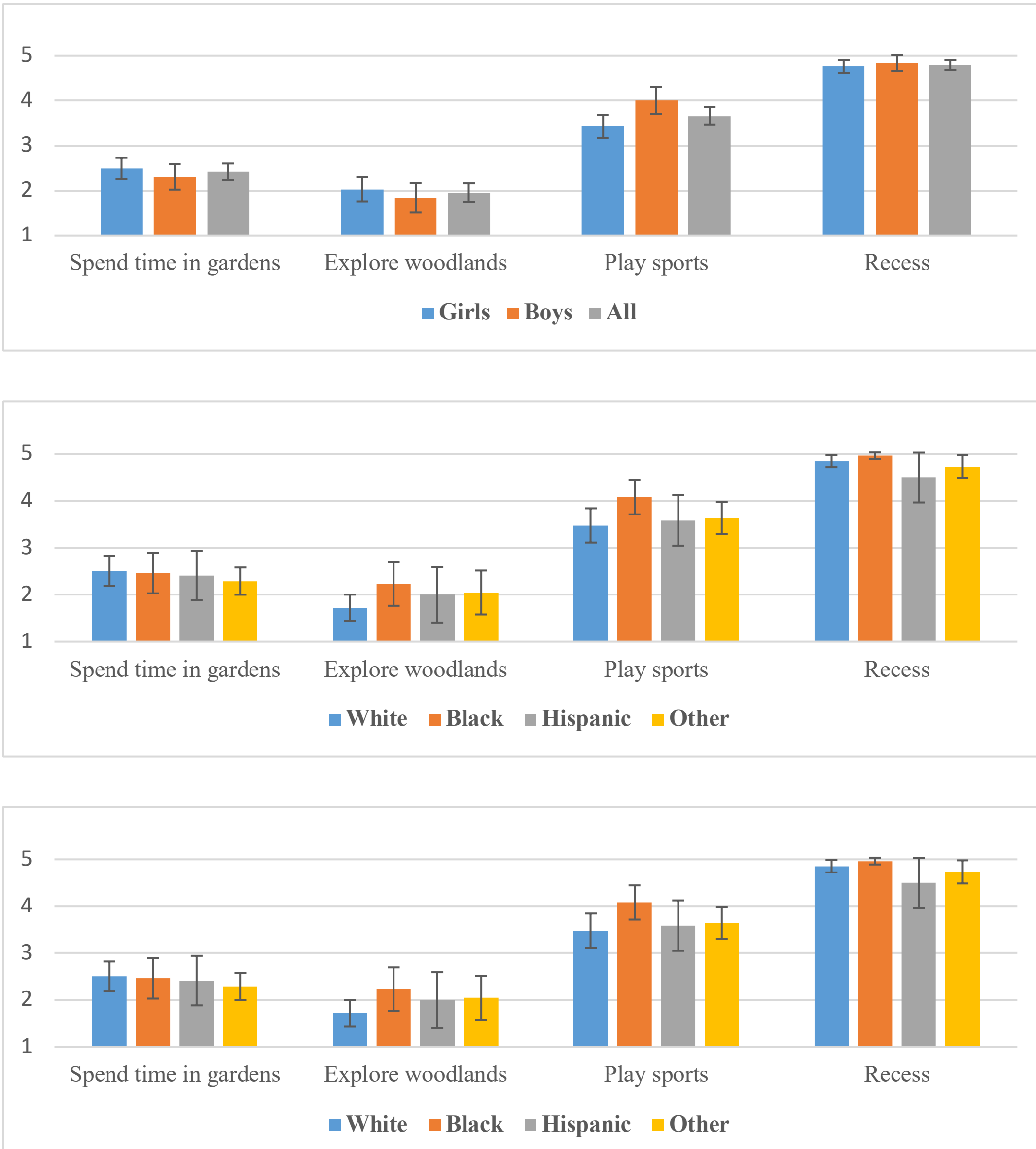

Figure 3. Frequency of students' self-report activities in their schoolyards by gender, race/ethnicity and grade, coded in 1-5 scale (Never, Once or twice a year, About once a month, About once a week, Several times a week) with 95% confidence interval.

Table 9. The percentage of schools have a certain green space type and the percentage of students and teachers from schools with corresponding green space type know this green space type existing in their schoolyards, standard deviation (SD) in bracket.

	Garden	Woodland	Playground	Athletic field
Schools (n=9)	66.7	33.3	88.9	100
Students	68.9 (46.4)	27.7 (44.5)	73.2 (44.4)	76.9 (41.4)
Teachers	100.0 (0.0)	66.7 (50.6)	100.0 (0.0)	92.8 (26.7)

Table 10. Predictors of the awareness of green space types in schoolyards among students (n = 205), including a nested random effect for teachers in generalized regression model.

Green spaces	**Variable**	**Beta**	**SE**
Garden	Frequency taking kids outdoor	**0.37****	0.19
	EE workshop experience	**0.90**	0.51
	Garden presence	**2.21*****	0.6
	R^2	0.398	
Woodland	Frequency taking kids outdoor	0.06	0.21
	EE workshop experience	-0.48	0.57
	Woodland presence	**1.24****	0.56
	R^2	0.169	
Athletic field	Frequency taking kids outdoor	-0.21	0.18
	EE workshop experience	-0.13	0.48
	Athletic field presence	-	-
	R^2	0.102	
Playground	Frequency taking kids outdoor	**-0.30***	0.14
	EE workshop experience	0.09	0.39
	Playground presence	**2.48*****	0.76
	R^2	0.176	

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

Table 11. Predictors of activities among students, including a nested random effect for teachers.

Activities	Variable	Beta	SE
Spend time in gardens	Frequency taking kids outdoor	0.17	0.23
	EE workshop experience	0.35	0.51
	Children learn in gardens	0.04	0.06
	Garden presence	0.18	0.58
	Gender: Boys	**-0.35***	0.16
	Race: Black	0.20	0.24
	Race: Hispanic	-0.14	0.28
	Race: Other	-0.03	0.2
	R^2	0.369	
Explore woodlands	Frequency taking kids outdoor	0.08	0.09
	EE workshop experience	**0.67***	0.28
	Children learn in wood	**0.14'**	0.08
	Woodland presence	0.15	0.28
	Gender: Boys	-0.07	0.22
	Race [a]: Black	0.43	0.34
	Race: Hispanic	-0.11	0.41
	Race: Other	**0.52'**	0.28
	R^2	0.15	
Playing sports	Frequency taking kids outdoor	0.02	0.16
	EE workshop experience	-0.02	0.15
	Children learn in athletic field	0.04	0.08
	Athletic field presence	-	-
	Gender: Boys	**0.50****	0.20
	Race: Black	**0.75****	0.3
	Race: Hispanic	0.08	0.34
	Race: Other	0.25	0.25
	R^2	0.154	
Recess	Frequency taking kids outdoor	-0.04	0.04
	EE workshop experience	0.19	0.13
	Learn in playground	-0.01	0.04
	Playground presence	0.16	0.24
	Gender: Boys	0.09	0.08
	Race: Black	0.13	0.11
	Race: Hispanic	**-0.28***	0.13
	Race: Other	0.04	0.10
	R^2	0.126	

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

4. Significance to North Carolina and Funding Programs

We present a novel pathway to both expand GI throughout municipalities (i.e., working through school districts) and simultaneously document diverse benefits to water systems and human health and well-being. The overall aim is to provide cross-sector support for GI, to address stormwater challenges while also building environmental literacy & engagement. Our findings show that though there is opportunity to expand GI on schools, public elementary schoolyards provide equal exposure to GI, 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 were 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 GI actions.

5. Publication in process

Zhang, Z., Martin, K., Stevenson, K.T., & Yao, Y., (2021) Schoolyards as sources of green equity: understanding spatial and demographic distribution of urban green infrastructure. *Landscape and Urban Planning*. (Under 2nd Review)

Zhang, Z., Stevenson, K.T., Martin, K., (2021) Diversifying green spaces in schoolyards improve children's perception of school and affective response to being there. *Environmental Education Research.* (Submitted)

Zhang, Z., Stevenson, K.T., Martin, K., (2021) How schoolyards are being used for children-nature connection: understanding the influence of school ground truth and teachers' PD on children's nature-based activities. (In preparation)

6. Conference Presentations

Zhang, Z., Martin, K., Stevenson, K.T., & Yao, Y., (2020, May). *Schoolyards as a source for green equity: Understanding the spatial and demographic distribution of urban green infrastructure*. Oral presentation at International Association for Landscape Ecology Annual Virtual Meeting.

Zhang, Z., Stevenson, K.T., Martin, K., (2021.3 expected) *Diversifying green spaces in schoolyards improve children's perception of school and affective response to being there*. WRRI (Lightening Talk).

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