Title: Green urban landscapes and school-level academic performance

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Abstract:

The growing disconnect between humans and nature has implications for human well-being. Research has linked exposure to nature with various benefits including improved focus, vitality, productivity, and reduced stress, factors that may enhance the academic performance of individual students. In intensively-urbanized landscapes with few natural elements this effect could, via aggregated population-level impacts, influence the academic performance of entire populations, negatively affecting educational attainment and propagating urban poverty. Designing urban environments to provide increased interaction with natural landscape elements such as vegetation could mitigate this effect, benefiting the academic growth and future success of urban students. Recent studies support this idea; however, this effect is poorly understood, hindering the management of urban environments to improve educational outcomes. This study explores relationships between urban nature and the academic performance of urban schools using the Twin Cities Metropolitan Area of Minnesota, USA as a case study area. We used regression analysis to identify relationships among environmental variables on and around school campuses (i.e., tree cover, vegetated land covers, water) and four measures of population-level third-grade reading and mathematics success, accounting for school socioeconomic and demographic characteristics. Contrary to expectations, we found a positive relationship between impervious surfaces and reading performance, while relationships between two vegetated land covers (grass, shrub) and water bodies and both mathematics and reading academic success were non-significant. We found a significant, positive relationship between tree cover and reading performance, suggesting that initiatives aimed at increasing tree cover in student environments could support academic success.

1. Introduction

Today's populations inhabit increasingly urban environments. Over half of the world's population is now urban, a number that is projected to grow to 70% by 2050 (UNPD, 2012). This progressively more urban population is increasingly disconnected from the natural world, given the shift in the typical person's daily environment from largely natural (i.e., vegetated) to built. "Nature-deficit disorder" (Louv, 2008), a phrase used to describe the costs to human well-being associated with separation from the natural world, is of particular concern for the development of children in this urban world. The relationship between children and natural systems is recognized as critical to their development, influencing spiritual and cognitive growth, and mental and physical well-being (Kahn & Kellert, 2002; Kellert, 2005, 2009). The current disconnect between urban children and natural systems thus has major implications for their present and future well-being (Kellert, 2009; Kimball et al., 2009). Of particular concern are impacts on cognitive functioning and development associated with reduced contact with nature in urban settings that could limit academic performance and success in life. In intensively-urbanized landscapes, settings where most children have little to no contact with nature, this could affect not only individual students, but entire populations, propagating urban poverty via negative impacts on cognitive development and educational attainment. Remedying this disconnect by designing and managing urban landscapes to increase opportunities for interaction with nature (e.g., through the provision of parks and vegetation) could serve to enhance academic success and the overall well-being of urban populations. Very little empirical evidence exists to support this notion, however, reducing our ability to plan and design urban landscapes to enhance educational success.

Present research supports the idea that urban blue and green environments, waterways, and vegetated environments in urban settings benefit human well-being. Existing studies indicate that these environments enhance physical health (Kardan et al., 2015; Wheeler et al., 2015; White et al., 2013a), mental health (Bratman et al., 2015; Berman et al., 2012; Ryan et al., 2010), and cognition as well as attentive capabilities (Dadvand et al., 2015; Faber-Taylor & Kuo, 2011). Research has linked exposure to urban vegetated environments with improved focus, increased vitality, and reduced stress levels (Bratman et al., 2012). These findings imply that spending time in or around nature or natural landscape elements could indeed positively affect educational outcomes for individual students through improvements to cognitive and emotional well-being, as stress (Mathewson et al., 2012), in addition to reducing ability to direct attention thereby negatively impacting executive functioning (Kaplan & Berman, 2010), may thus lead to diminished academic performance.

Since the academic performance of individual students attending the same school aggregates to determine the academic performance of that school, access to green environments on school grounds or in school attendance areas (SAA) could thus enhance both student and school-level academic success while lack of such access could hinder success. This in turn could influence the future well-being of urban populations via impacts on employment and socioeconomic status associated with poor educational outcomes (e.g., failing to complete high school). This notion is particularly interesting in the context of intensively-developed urban environments with little vegetation or green space; environments where student academic performance, particularly that of disadvantaged groups, is often poor (Blanchett et al., 2005). The limited evidence that exists in this area indicates that nature on and around school campuses can indeed impact the academic performance of entire student bodies. For example, high schools

with views of trees and shrubs have been found to have higher average standardized test scores and graduation rates, more students going to college, and lower delinquency rates than other schools (Matsuoka, 2010). Additionally, levels of vegetation around schools have been found to exhibit a positive association with third-grade reading and mathematics scores on standardized tests (Wu et al., 2014). The connection between urban nature and school-level academic performance, however, is currently under-explored, and defining relationships between urban vegetation and school performance will require considerably more research. Key questions that remain center on identifying the locations in which natural landscape elements impact student performance (i.e., on-campus, near campus, in the home environment), how different natural landscape elements influence academic performance, and the levels and types of exposure to nature that relate to student academic performance. Answering these questions will help us better understand relationships between urban nature and academic performance and thus benefit urban populations via design and management of urban landscapes.

In order to improve our understanding of the relationship between academic performance and exposure to nature in urban landscapes, this study sought to identify associations between school-level reading performance and levels of vegetation on school campuses and in SAA. SAA are exhaustive spatial partitions of school districts delineated by district administrators. The relationship between school, student, and SAA is such that a student attends the school associated with the SAA in which they live. Although these boundaries usually ensure that students attend the school closest to their residence, school districts may manipulate them with the goal of impacting segregation (Richards, 2014). Utilizing SAA over open enrollment can reduce commute lengths thereby potentially reducing student stress (Masouleh, 2009); furthermore, living in close proximity to school may encourage students to walk or bike to class,

creating opportunities for exercise. We deemed this unit of geographical analysis appropriate for this study because it provides an indicator of the environment in which elementary school students spend their time away from campus (i.e., their residence and immediate neighborhood).

We focused on urban schools in the Minneapolis-St. Paul metropolitan area of Minnesota, USA and examined relationships between academic performance as indicated by mean standardized test scores for individual schools and measures of urban nature (tree cover, impervious surfaces, and waterways) for school campuses and SAA. We focus on reading test scores at the third-grade level as third-grade reading ability predicts odds of high school graduation and college enrollment (Lesnick et al., 2010). Based upon past studies, we hypothesized that a positive association would exist between mean school test scores and the levels of tree cover and areas of waterbodies on campus and in SAA given that evidence exists to suggest that these features reduce student stress and enhance focus. We further hypothesized that a negative relationship would exist between urban intensity as indicated by imperviousness and test scores as these environments would likely offer fewer opportunities to interact with nature. In this way, we sought to elicit relationships between urban environmental characteristics and school-level academic performance. Identification of these relationships will not only improve our understanding of the relationship between school performance and urban nature, but will also enhance our ability to plan and manage green environments to support well-being.

2. Urban green environments and academic performance

2.1. Theoretical frameworks for interpreting relationships between exposure to nature and academic performance

Understanding the links between urban green environments and the performance of individual schools requires us to consider the mechanisms through which green environments may enhance the academic performance of individual students. Past studies of the relationships among exposure to nature, cognitive ability, and emotional well-being indicate that green environments may impact academic performance through mechanisms explained by two existing theories, Attention Restoration Theory (ART, see review by Kaplan & Berman, 2010) and Stress Recovery Theory (SRT; Ulrich et al., 1991). The first explains how nature and cognition may interact to influence academic performance. The second suggests that humans have evolved a psycho-physiological response to nature such that spending time in natural environments lowers stress. We summarize these theories and their implications for academic performance below.

2.1.1. ART: Nature and the ability to direct attention

ART holds that the mechanism necessary to voluntarily direct attention, an ability crucial to higher-level cognitive functioning and behavioral regulation, may become fatigued. Restoration of this mechanism can occur when an individual has an opportunity to rest through time spent in a restorative environment. This kind of environment has the following four characteristics: (1) it attracts attention involuntarily while allowing for thoughtful reflection, (2) is welcoming (e.g., is not irritating or dangerous), (3) encourages exploration of the environment, and (4) offers a feeling of separation from normal attentional demands (i.e., a feeling of “getting away from it all”). From this perspective, natural environments may enhance academic performance through their capacity to restore an individual’s ability to voluntarily direct attention. As such, time spent in green environments would serve to restore an individual’s ability to focus on academic tasks and thus their overall ability to learn and perform these tasks.

Under ART, students exposed to green environments may be able to focus more effectively for longer periods of time and thus should experience enhanced school performance compared to students without such exposure. Existing research focused on individuals supports this assertion. The attentive benefits of nature, for example, appear to reduce symptoms of attention deficit disorder for both individuals and entire populations (Faber-Taylor & Kuo, 2009, 2011). College students unfamiliar with the concept of ART consistently rated environments with natural features as more effective locations to take a break from studying in general, and when asked to rate these environments in terms of the four characteristics of a restorative environment, researchers found that the environments rated most effective for taking a study break were also rated highly across these four characteristics (Felsten, 2009). The mere presence of natural elements in an environment has also been found to mitigate mental fatigue during work that demands a considerable degree of focus (Berman et al., 2008; Raanaas et al., 2011).

These findings provide support for the idea that the restorative effects of natural environments are linked to enhanced individual academic performance. They suggest that the restorative characteristics of nature as described by ART contribute to the effectiveness of a space as a place to recover from mental fatigue. This in turn enhances an individual's ability to focus and perform tasks. These restorative effects could thus lead to better individual academic performance, and, in aggregation, to higher school-level performance in urban settings with greater exposure to nature.

2.1.2. SRT: Nature and stress recovery

SRT suggests that exposure to nature allows for recovery from stress through evolutionary responses to particular attributes of natural environments, such that the perception of these attributes results in positive feelings related to safety and survival (Bowler et al., 2010).

A number of studies indicate that nature can effectively reduce stress. Lottrup et al. (2013) found that both physical and visual access to workplace greenery reduces stress directly and indirectly by positively influencing workplace attitude. Urban gardens have been found to act as spaces for relaxation, providing a means to temporarily escape from stressful situations (Freeman et al., 2012). These stress recovery benefits of nature appear to act separately from benefits involving attention restoration. For example, walking in nature corresponded to independent improvements in mood and memory, which are characteristics related to stress and attentive function respectively, in subjects with major depressive disorder (Berman et al., 2012). Furthermore, the stress reduction and attention restoration effects of exposure to nature were found to operate through different pathways in high school students (Li & Sullivan, 2016).

Studies of relationships among tree canopy and other natural features and stress levels further support the notion that exposure to nature reduces stress. Positive relationships have been observed between self-reported stress recovery and street tree density in videos of street tree scenes (Jiang et al., 2016). This effect may vary with gender, although studies to date are not consistent in their findings, perhaps due to differences in study design. Some studies measuring stress recovery during full immersion in restorative environments, for example, found that time spent in or viewing nature benefits men less than women or not at all in terms of stress levels (Beil & Hanes, 2013; Roe et al., 2013). Another study that considered stress recovery while viewing videos of different neighborhood street, however, indicated that only male subjects experience lower stress levels when exposed to greener environments (Jiang et al. 2014). The significance and direction of this effect may also vary with amount of vegetation in an environment as stress recovery was found to exhibit a curvilinear relationship with tree cover density, increasing to a certain point (24%), remaining unchanged between 24% and 34% cover

density, and thereafter to decreasing in a study in the Midwestern US (Jiang et al. 2014). Stress recovery may also depend not only on quantity, but also on quality of tree cover such that streets with higher quality greenery as determined by factors such as variability and maintenance levels have residents with significantly lower levels of perceived stress (De Vries et al., 2013). Furthermore, a study of landscape preference found that preference for residential street scenes increases with tree cover density to a certain extent, but gradually lessens thereafter (Jiang et al. 2015). Also, while exposure to nature may reduce perceived stress levels, this effect may not necessarily reduce stress levels as measured chemically (e.g. by cortisol concentrations in saliva) (Tyrvaenen et al. 2014). Thus while studies support the idea that exposure to nature positively influences stress recovery, this relationship may be complex, exhibiting non-linearity and variation with quality and quantity of exposure. Thus similarly complex associations may exist with respect to the influence of exposure to nature on academic performance via stress reduction.

2.1.3. Nature, vitality, and affect

In addition to enhancing student performance, natural environments may also positively influence vitality and affect. Spending time in nature appears to lead to a sense of energy and awakening, as well as “here-and-now” thinking (i.e., being alert, aware, and focused), both characteristics of elevated vitality (Kjellgren & Buhrkall, 2010). Individuals who regularly spend more time in nature report significantly higher levels of daily vitality (Ryan et al., 2010) as well as feelings of revitalization (White et al., 2013b). Research also indicates that neighborhood greenness enhances neighborhood satisfaction such that residents are more satisfied when they have access to natural features immediately surrounding their home, particularly when they can see nature from their living rooms, and are significantly happier as a result (Van Herzele & De Vries, 2011). Thus individuals who are exposed to natural environments may have more energy,

more positive emotional states, and therefore an enhanced sense of well-being. These individuals might thus be better able to learn and perform academic tasks than individuals without such exposures.

2.2. Natural environmental features and school-level academic performance

At present, only two studies have explored relationships between the academic performance of schools and exposure to natural environmental features. Matsuoka (2010) explored relationships between the percentages of students receiving merit-based awards, planning to attend college, and graduating from high schools in southeastern Michigan, USA and on-campus exposure to nature as indicated by views of nature from classrooms and cafeterias and levels of vegetation in school landscapes. Results of this study indicated a positive relationship between exposure to nature and student performance such that views that included trees and shrubs exhibited a positive association with test scores, graduation rates, and college attendance, and a negative relationship with criminal behavior. Additionally, school landscapes that included large expanses of intensively-managed features such as lawns, athletic fields, and parking lots showed a negative relationship with test scores and college plans. This study thus supports the idea that increased nature on school campuses, particularly trees and shrubs, enhances academic performance at the school level. However, as this study did not focus on urban schools, it cannot tell us specifically how exposure to nature influences student success in urban environments. Similarly, this study focused solely on student exposure to nature within the school environment. Student exposure to nature off-campus, at home, and in student neighborhoods might also influence student success and warrants examination.

A second recent study examined relationships between the performance of Massachusetts elementary schools on standardized tests and greenness in neighborhoods surrounding schools (Wu et al., 2014), finding a positive association between levels of vegetation around schools and third-grade reading and mathematics standardized test scores. Here, greenness in neighborhoods surrounding schools exhibited a positive relationship with standardized test performance. This relationship was particularly significant in the spring which coincides with the timing of standardized test administration, and exhibited nearly equal effects amongst different genders and economic statuses. This study thus supports the notion that neighborhood greenness benefits the academic performance of schools and can do so across socioeconomic and gender groups. However, due to a lack of detail in the components of greenness examined, it does not enable us to identify specific types or arrangements of vegetation that are related to enhanced performance. Like Matsuoka (2010) the authors of this study also focused on schools in general, not on urban schools, so their results shed little light on these relationships in exclusively urban environments. Lastly, in identifying school neighborhoods, these authors used circular buffer areas around schools, not actual SAA. Thus, because SAA frequently are not centered on the school location itself, it is likely that these buffers are somewhat inaccurate in their representation of student environments. Utilizing actual SAA would better approximate the exposure to nature members of a student body experience in their day-to-day lives, thus helping to elicit more precisely the relationships among urban nature and school performance.

Collectively, these studies begin to answer questions regarding beneficial relationships between nature and school performance that may be related to the effects of exposure to nature on recovery from stress and mental fatigue. Although these studies have made a significant contribution to our understanding of these relationships, a need exists to explore said

relationships in an urban context and to more accurately represent student environments in future studies. The present study seeks to address these needs, thereby improving our understanding of the relationships between exposure to urban nature and academic performance, understanding that could facilitate the design and management of urban landscapes to enhance student success in urban settings.

3. Material and Methods

We investigated the relationship between natural elements of urban landscapes and the third-grade reading and mathematics test scores of 222 primary schools in the Twin Cities Metropolitan Area (TCMA) of Minnesota, USA for the 2010-2011 academic year. The TCMA covers a seven-county area that includes the cities of Minneapolis and St. Paul (Figure 1), and is characterized by a socioeconomically and demographically diverse population. The area had a population of approximately 3,459,146 in 2010 with approximately 10% of that population living below the poverty line according to the US Census. The urbanized area of the TCMA during that academic year included 292 SAA. These SAA varied in the economic status of their populations with school-level free or reduced priced lunch eligibility ranging from 1% of the student body to over 70% (U. S. Department of Education, 2012). Numerous ethnic and racial groups are represented in school populations and vary greatly in their proportions from school to school with, for example, the proportion of non-White third graders at a given school varying from 3.57% to 98.51% during the 2010/11 academic year (mean = 39.98%). Additionally, the TCMA landscape includes land uses and land covers ranging from vegetated types such as forest and agriculture to intensively-developed types, among them industrial, high-density developed, and commercial types. As such, this study area is typical of many large American metropolitan

areas, making it an excellent location in which to explore the relationship between natural elements of urban landscapes and academic performance.

<Figure 1>

Since our work focused on third-graders in urban environments, we considered only those elementary schools with SAA that exceeded 50% urban land. We used urban extents delineated by the 2010 Census in combination with SAA boundary files from the Minnesota Population Center (The College of William and Mary and the Minnesota Population Center, 2011) to identify SAA that met this criterion. We thus identified a total of 248 SAA; however, 9 schools had incomplete data for one or more study variables, and 17 schools were magnet schools that draw students from a variety of neighborhoods, which frustrates identification of the locations where students attending those schools live. We excluded these 26 schools from our analysis, generating a final sample size of 222.

We calculated a series of variables known or thought to influence academic performance for each school in our sample (Table 1). We quantified the academic performance of individual schools using reading and mathematics test results from the 2011 Minnesota Comprehensive Assessment (MCA) available from the Minnesota Department of Education (<http://education.state.mn.us/MDE/Data/>). This standardized test is offered annually to all Minnesota students to measure student progress toward achieving academic standards and includes reading and mathematics exams for grades three through eleven, and science exams for grades five, eight, and nine through twelve. We chose to focus on third-grade reading test scale scores and the proportion of third grade students exceeding basic standards (proficient) in reading ability as third-grade reading ability has been found to predict future academic success (Lesnick et al., 2010) and thus identifies the potential future well-being of school populations.

We additionally examined mathematics scores and the proportion of third grade students exceeding basic standards in mathematics ability, as prior research suggests exposure to nature may have a beneficial influence on mathematics performance (Wu et al., 2014). “Proportion exceeding” refers to the percentage of students classified as exceeding a basic standard according to the Minnesota Department of Education. This classification is determined by student scores on the MCA where a scale score of 65 or higher out of 99 indicates that students have exceeded standards (the means of school average scale scores for reading and mathematics in our sample are 64.04 and 56.88 respectively). We used 2011 MCA score reports by grade and school to obtain the mean reading and mathematics scores of third-grade students attending each school in the study sample in addition to the proportion of students exceeding the basic standard for reading ability and mathematics at said schools.

< Table 1 >

Socioeconomic and demographic factors are known to influence academic success and we included a series of variables to account for these effects. First, a gap in academic achievement exists among students of low, medium, and high socioeconomic status (SES), as well as among English language learners (ELL) and native speakers (U. S. Department of Education, 2013). Furthermore, race and ethnicity influence academic performance (Davis-Kean & Jager, 2014). We used National Center for Education Statistics’ Common Core of Data for the 2010-2011 school year (U. S. Department of Education, 2012) to estimate the percentage of students eligible for free or reduced lunch at each school (i.e., students with household incomes 185 percent of the poverty threshold or lower) to indicate the level of poverty in a school population. We also used this dataset to identify the racial (Black, Asian) and ethnic (Hispanic) composition of the third-grade student population at each school. We identified the percentage of

third graders that were ELL at each school based on data from the Minnesota Department of Education (<http://w20.education.state.mn.us/MDEAnalytics/Data.jsp>).

We estimated five environmental variables to indicate the level of greenness and the development intensity of each SAA. We calculated two of these variables (grass cover, shrub cover) based on the United States Geological Survey (USGS) National Land Cover Dataset (NLCD) for 2011 (Homer et al., 2015). We used a related product, the NLCD 2011 United States Forest Service Tree Canopy cartographic product, a dataset that identifies percent canopy cover for the lower 48 states of the USA at a 30 meter resolution (Homer et al., 2015), to calculate the mean percent canopy cover in each SAA in a geographic information system (GIS). Similarly, we used the 30 meter resolution NLCD 2011 Percent Developed Imperviousness dataset (Homer et al., 2015) to calculate mean impervious surface percent coverage for each SAA. We estimated an additional environmental variable, the percentage each SAA covered by waterbodies, to identify the potential level of exposure of students to waterbodies in their day-to-day lives. We calculated this variable using the USGS high-resolution National Hydrography Dataset (<http://nhd.usgs.gov>).

We initially estimated four ordinary least squares (OLS) regression models to identify relationships among the variables described above and third-grade reading test score (hereafter, model 1), the percentage of third grade students exceeding the basic reading standard i(hereafter, model 2), third-grade mathematics test score (hereafter, model 3), and the percentage of students exceeding the basic standard in mathematics (hereafter, model 4). Spatial autocorrelation (SAC) refers to the tendency of features and their associated data values to cluster together in space. SAC of residuals may complicate OLS models by violating the assumption of error independence. SAC may occur in the lag term, that is, in the dependent variable, in the error term

(e.g., due to the omission of a predictor variable with spatial structure), or both. A number of techniques exist for addressing such SAC, among them spatially-simultaneous autoregressive (SAR) models. SAR models address SAC by adding one or more terms to represent the spatial structure of autocorrelation (Cressie, 1993; Haining, 2003). The implementation of such models requires a spatial weights matrix to identify the influence of each neighbor upon a given observation. Such weights matrices are typically defined based upon distance or contiguity such that more proximate neighbors exert a greater influence than more distant neighbors via higher weights (Fortin & Dale, 2005).

We tested for residual SAC using Moran's I and Lagrange multiplier diagnostics for spatial dependence. We conceptualized neighbors as those SAA sharing more than one point along their borders (rook contiguity), as queen contiguity, which involves only one shared point (i.e. a corner), would be likely to misrepresent neighbor relations among SAA given their highly complex and irregular shapes. The results of these tests indicated no significant residual SAC in models 1, 3, and 4, allowing us to use the OLS results for those models. Results for model 2, however, indicated the presence of significant residual SAC in the lag term ($LM_{err} = 1.7646$, $p > 0.05$; $LM_{lag} = 5.5377$, $p < 0.05$) so we estimated a SAR lag model to address this issue. The SAR lag model supplements the OLS regression model with an additional term, ρWY , such that:

$$Y_i = X\beta + \varepsilon_i + \rho WY \quad (1)$$

Here, Y is the dependent variable, ε_i is an error term, ρ is the autoregression coefficient, and W is the spatial weights matrix. We also tested for heteroscedasticity, or non-constant variance, which violates the assumption of homoscedasticity, using a Breusch-Pagan test. Results indicated significant heteroscedasticity in model 1 and model 2 ($p < 0.05$), thus we adjusted our standard errors following White's method (White, 1980).

4. Results

4.1 Bivariate relationships among environmental variables and academic performance.

We first examined bivariate relationships among environmental variables and the four measures of academic performance using scatterplots and Pearson correlation coefficients (see Appendix for coefficients). These scatterplots indicate that, considered independently of other influential factors, the average percentage of canopy cover in an SAA has a positive association with average score and percentage of students exceeding the basic reading standard respectively (Figures 2-3). Additionally, a negative bivariate association exists between the average percentage of impervious cover and the respective dependent variables (Figures 4-5). We found similar bivariate relationships with the dependent variables measuring mathematics performance (Figures 6-9). These results are in accordance with our expectations and suggest that student bodies do experience improved academic success in environments with greater exposure to nature.

< Figure 2 >

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< Figure 8 >

< Figure 9 >

4.2. Regression results.

Table 2 summarizes our OLS model for reading score (model 1) and the SAR lag model for proportion of students exceeding the basic standard for reading (model 2). Table 3 summarizes the models for mathematics score (model 3) and proportion of students exceeding the basic standard for mathematics (model 4). Due to multicollinearity among race and ethnicity variables and free or reduced price lunch eligibility, which exhibited stronger relationships with the dependent variable, we removed race and ethnicity variables from our final models. The resulting OLS models exhibited high model fit (model 1 adjusted $R^2 = 0.839$, $p < 0.001$; model 2 adjusted $R^2 = 0.8172$, $p < 0.001$; model 3 adjusted $R^2 = .7527$, $p < 0.001$; model 4 adjusted $R^2 = .6284$, $p < 0.001$), but model 2 suffered from significant residual SAC in the lag term, so we estimated a SAR lag model as detailed above. This model improved upon the original OLS model as indicated by a reduced AIC (1534.4 versus 1537.8 for the OLS model) and a significant autoregression coefficient ($\rho = 0.13$, $p < 0.05$), and explained approximately 82.73 percent of the variation in the proportion of students exceeding the basic standard for reading, however, the BIC for both the OLS and SAR models are the same.

< Table 2 >

<Table 3>

Coefficients for school-level socioeconomic and demographic variables exhibited a significant relationship to mean school MCA reading test score in the expected direction. The proportion of students eligible for free or reduced-price lunch at a school exhibited a negative relationship with MCA reading score ($\beta = -0.2781$, $p < 0.001$) such that schools with a higher percentage of eligible students experienced lower scores (U.S. Department of Education, 2013). The relationship between mean MCA reading score and the proportion of ELL in a school

population was also negative ($\beta = -0.0785, p < 0.05$), which further agrees with findings from the U. S. Department of Education (2013).

Two of the environmental variables included in this study were significantly related to school mean reading test scores. Mean canopy cover was, as expected, positively related to mean MCA score ($\beta = 0.1211, p < 0.05$) such that schools with higher levels of canopy cover had higher mean test scores. We found an unexpectedly positive and significant association between level of imperviousness and reading performance ($\beta = 0.0998, p < 0.05$), indicating that schools with higher imperviousness (i.e., higher intensities of urbanization) in their attendance areas experienced higher mean test scores. This multivariate association is opposite the observed bivariate one described above and suggests that there are features of the built environment positively influencing reading achievement, but that this influence is not apparent without accounting for the effects of SES and ELL status. The associations between grass cover, shrub cover, and mean SAA reading test score were not significant ($p > 0.05$). The relationship between mean reading test score and percent cover of water was, as predicted, positive ($\beta = 0.0609$), but was not significant at the 95% confidence level ($p < 0.10$).

School-level socioeconomic and demographic variables were significantly related to the proportion of students exceeding the basic reading standard in model 2. The proportion of students exceeding the basic standard for reading was negatively related to the proportion of students eligible for free or reduced price lunch ($\beta = -0.5388, p < 0.001$), and to the proportion of ELL students ($\beta = -0.1905, p < 0.01$). As in model 1, levels of both imperviousness and canopy coverage exhibited significant, positive relationships with the dependent variable such that as the proportion of built surfaces in an SAA increased, so too did the proportion of students exceeding the basic standard for reading ($\beta = 0.2304, p < 0.05$). A similar effect existed with respect to the

degree of canopy cover in an SAA ($\beta = 0.2685, p < 0.05$). The percentages of grass, shrub, and water cover in an SAA were not significantly related to the dependent variable ($p > 0.05$).

Results for the mathematics models were similar in regard to SES, with score and the proportion of students exceeding the basic mathematics standard showing a significant negative relationship with the proportion of students eligible for free and reduced lunch ($\beta = -0.2146, p < 0.001$ and $\beta = -0.4193, p < 0.001$ respectively). However, while the proportion of ELL students had a significant negative association with mathematics score ($\beta = -0.0548, p < 0.05$), we found no significant association between that variable and the proportion of students exceeding the basic standard for mathematics. No other independent variables were significantly associated with either mathematics performance measure. These results suggest that influences other than those of the natural and built environment affect performance in mathematics and are not in agreement with the findings of Wu et al. (2014) previously discussed.

5. Discussion

Past studies found positive relationships between exposure to nature and academic performance at the school level (Matsuoka, 2010; Wu et al., 2014). Possible mechanisms for these effects may relate to attention restoration and stress reduction brought about by exposure to nature (Berman et al., 2008, 2012; Bowler et al., 2010; Faber-Taylor et al., 2011; Felsten, 2009; Freeman et al., 2012; Kjellgren & Buhrkall, 2010; Lottrup et al., 2013; Raanaas et al., 2011; Ratcliffe et al., 2013; Ryan et al., 2010; Van Herzele & De Vries, 2011; White et al., 2013a) and exposure to nature in urban landscapes may thus benefit academic performance. However, questions about mechanisms whereby this relationship operates remain unanswered, particularly regarding the relationships between different types and locations of natural features and

academic performance. This study sheds new light on these relationships, identifying key associations between specific elements of urban nature (i.e., trees, development intensity) and school-level third-grade reading performance.

Our findings indicate that tree canopy is positively related to school-level reading performance after accounting for school SES and demographic characteristics and are consistent with the work of Wu et al. (2014), which found a positive association between green school surroundings and third-grade reading performance. Although more research is needed to draw definitive conclusions, these findings lend support to the idea that nature in urban SAA may influence school-level academic success. Our results, however, cannot identify the processes whereby this influence occurs. Stress reduction and attention restoration could produce restorative effects, thereby positively influencing the ability of individuals to focus on and complete learning tasks, enhancing individual reading performance, and, in aggregate, the reading performance of the schools these individuals attend. Additional research is needed to identify whether these or some other processes are behind the relationships observed here.

We did not find a significant association between canopy cover and mathematics performance. Thus, at the school level, reading, but not mathematics performance appears to be related to exposure to urban nature. This finding is contrary to that of Wu et al. (2014) who found positive associations between greenness and performance on standardized mathematics examinations. Differences in the tests administered, in student populations, or in environments among the two studies might contribute to these dissimilar findings. Further study is needed to definitively identify relationships among mathematics performance and urban green settings as well as the factors that shape these relationships.

Contrary to our expectations, we found no significant relationships between water in student environments and any measure of school-level academic performance. This result may stem from a failure to identify water in a manner that adequately identifies student exposure to water bodies in that our measure does not identify whether water bodies are visible or accessible to students and ignores water body type and water quality. This relationship warrants future exploration, particularly as recent studies have found positive impacts of water in urban residential environments on self-perceived general mental and physical health (Wheeler et al., 2015; White et al., 2013a) that could influence academic performance.

The level of imperviousness in an SAA exhibited an unexpected, positive and significant relationship with both measures of school reading performance. This association presents an opportunity for future work, given the lack of research exploring relationships among the built urban environment on academic performance. Future studies might explore these relationships further by measuring novel variables to represent built features of urban setting such as performing arts venues, museums, libraries, and playgrounds that could enhance school performance.

We found the above-described relationships between urban nature and academic performance while accounting for the demographics and SES of school populations. The signs and significance of the coefficients for these demographic and SES variables were as expected and in agreement with existing literature. We attempted to include variables related to race and ethnicity, but found that these variables were highly collinear with free or reduced price lunch eligibility, a better predictor, and thus removed them. The strong relationship among these variables suggests that incorporating free or reduced priced lunch eligibility adequately represents the SES of school populations and its effects. This combined with the correspondence

between the significance and direction of our demographic variable (percentage of ELL students) makes us confident that we have accounted for the effects of SES and non-native speaker status sufficiently. Future work may include additional SES variables, perhaps estimated from coarser-resolution Census data using interpolation techniques, to produce better models of the relationship between nature and academic performance.

Our study is the first to explore associations between nature and educational outcomes in urban environments using data at the SAA level in combination with relatively high-resolution spatial data. Because they identify the environments in which students reside and through which they travel to school, SAA extents should represent the environments students experience in their daily lives more accurately than the buffer areas or school-campus-level data used in prior research. The use of SAA in studies such as this one should thus lead to more accurate estimates of the association between urban nature and school performance. Prior research has provided insight into the scholastic benefits of nature both on and off-campus across urban and rural contexts simultaneously, but these benefits may be especially important for urban students. In exploring these relationships for urban schools alone, our study has begun to identify the aspects of urban nature such as tree cover that may be used to manage urban environments to support academic success.

This work has important implications for the planning and management of urban environments. Our results suggest that urban landscape design efforts that provide more exposure to vegetation in day-to-day student environments, particularly tree cover, could enhance third-grade reading performance, which, as a predictor of the probability of completing high school, could in turn enhance the well-being of future urban populations and reduce their burden of poverty. Future work that explores in greater detail the characteristics of urban nature

that are related to academic performance, the mechanisms by which this relationship occurs, and how the location of natural elements influences this performance could be particularly beneficial in identifying how to structure urban landscapes to support educational attainment, as would studies that explore how this relationship varies among different urban populations.

6. Conclusions:

In today's increasingly urban world, the growing disconnect between humans and nature may be detrimental to the development of urban children and as a result to the well-being of future urban populations. Reconnecting children with nature in urban settings could serve to remedy this problem. Past research suggests that exposure to nature can enhance concentration and reduce stress, which might lead to improved focus and performance on academic tasks. This study adds to the small, but growing literature that supports the idea that natural elements of urban environments can enhance student success. Our findings indicate that increased exposure to tree cover is related to increased performance on standardized reading tests and therefore higher proportions of students classified as exceeding the basic standard for reading, indicating a benefit to academic success at the school level. Thus, providing such exposures via the provision and maintenance of access to such features in urban environments could benefit the educational attainment of urban populations, enhancing both their present and future well-being.

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Tables

Table 1

Variable	Description	Mean	Median	SD	Min	Max	Expected Relationship
<i>Socioeconomic and demographic variables</i>							
Reading	MCA school average reading score (dependent variable)	64.04	65.35	8.21	38.8	82.3	N/A
ExcdR	Percentage of students exceeding the basic reading standard	53.39	56.1	17.68	6.1	88.4	N/A
Math	MCA school average mathematics score	56.88	57.8	6.99	37.1	72.9	N/A
ExcdM	Percentage of students exceeding the basic mathematics standard	30.57	30.75	14.23	0	72.2	N/A
Lunch	Percentage of students eligible for free or reduced lunch	39.31	36.06	25.07	2.54	98.17	negative
ELL	Percentage of English language learners	15.05	11.78	14.91	0	71.92	negative
<i>Blue and green space variables</i>							
Canopy	Mean % canopy tree cover in SAA	14.41	14.59	5.96	2.97	32.37	positive
Impervious	Mean % imperviousness in SAA	31.61	30.86	11.56	4.1	64.46	negative
Grass	% area grass cover in SAA	0.6	0.19	0.99	0	7.01	positive
Shrub	% area shrub-like vegetation in SAA	0.4	0.09	0.72	0	4.13	positive
Water	% area water bodies of SAA	5.38	2.96	7.66	0	49.5	positive

Table 2

Variable	Model 1.				Model 2.			
	β	SE	t-value		β	SE	t-value	
(Intercept)	71.0551	1.57344	45.160	***	59.2791	4.27007	13.883	***
<i>Socioeconomic and demographic variables</i>								
Lunch	-0.27805	0.02086	-13.330	***	-0.53878	0.04485	-12.013	***
ELL	-0.07848	0.03771	-2.081	*	-0.19053	0.07186	-2.651	**
<i>Blue and green space variables</i>								
Canopy	0.12107	0.04029	3.005	**	0.26846	0.10439	2.572	*
Impervious	0.09980	0.04117	2.424	*	0.23041	0.10132	2.274	*
Water	0.06087	0.03586	1.698		0.09138	0.09769	0.936	
Grass	0.02210	0.31515	0.070		0.02147	0.76224	0.028	
Shrub	-0.35873	0.47775	-0.751		-1.01216	1.36941	-0.739	
R-squared: 0.8441					Nagelkerke pseudo-R-squared: 0.8273			
Adjusted R-squared: 0.839					Rho: 0.12996, LR test value: 5.4066, p-value: 0.02006			
F(7, 214): 165.6, $p < 0.000$					ML resid. variance (sigma squared): 53.536, (sigma: 7.3169)			
					Log likelihood: -757.2168 for lag model			
					BIC: 1568.46 (BIC for OLS 1568.46)			
					AIC: 1534.4 (AIC for OLS: 1537.8)			

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 3

Model 3.				Model 4.				
Variable	β	SE	t-value		β	SE	t-value	
(Intercept)	65.3678	1.73331	37.713	***	44.4731	4.32945	10.272	***
<i>Socioeconomic and demographic variables</i>								
Lunch	-0.21461	0.01807	-11.876	***	-0.41929	0.04514	-9.290	***
ELL	-0.05485	0.02683	-2.044	*	-0.07390	0.06702	-1.103	
<i>Blue and green space variables</i>								
Canopy	0.03135	0.049	0.64		0.12792	0.12239	1.045	
Impervious	0.00752	0.04001	0.188		0.05141	0.09993	0.514	
Water	0.01431	0.03662	0.391		0.02619	0.09147	0.286	
Grass	0.16746	0.32042	0.523		0.28054	0.80034	0.351	
Shrub	-0.22426	0.3949	-0.568		-0.22076	0.98638	-0.224	
R-squared: 0.7605					R-squared: 0.6401			
Adjusted R-squared: 0.7527					Adjusted R-squared: 0.6284			
F(7, 214): 97.08, $p < 0.001$					F(7, 214): 54.38, $p < 0.001$			
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$								

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