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GIS analysis of urban schoolyard landcover in three U.S. cities

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Abstract Although there has been considerable interest in the rejuvenation and greening of inner-city schoolyards for several decades, recent studies on the behavioral and environmental impacts of greenspace, particularly tree cover, suggest that greenspace on schools may be more important than previously understood. However, little is known about the conditions and landcover of urban schoolyards. To understand the structure of the landcover on city schoolyards, this study used Geographic Information System software to classify and compare landcover on 258 U.S. public elementary and middle schools in Baltimore, MD, Boston, MA, and Detroit, MI. For all three cities, schoolyard was found to cover, on average, more than 68% of the school property, which was an average of 1.0–2.5 ha in size. Boston's schoolyards (circa 1995) were notably smaller from those in Baltimore and Detroit, and they had far more impervious surface. On average, schoolyards were dominated by turf grass and impervious surface, while tree canopy occupied the smallest fraction of schoolyard landcover (approximately 10%). In light of these findings, we conclude by discussing how greening might be achieved on these and other yards.

Keywords Schoolyard · Greenspace · Urban forest · Landcover · GIS

Introduction

Over the past several decades, there has been a growth of interest among educators, designers, and communities in rethinking the form of the urban public schoolyard, defined here as all the school property around the school building. Begun largely in the United Kingdom but quick to spread to Canada and the United States, this movement, has been

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motivated by the critique that many urban schoolyards are barren expanses of asphalt and other paved surfaces—a space that has been compared to a prison yard: well designed for exercise and surveillance and little else (Allen 1968).

Concern over the state of inner city schoolyards has been substantiated by a number of studies, many of them qualitative in nature, examining the impact of children's physical environs and play spaces on their development and mental health. For example, the complexity of play spaces (i.e. their provision of multiple and varied play opportunities) has been found to positively correlate with more creative play, and thus result in more dynamic thinking processes that support healthy development (Campbell and Frost 1985; Moore 1986). Increasing diversity in play areas, both in terms of space and equipment, has also been noted to reduce aggression and anti-social behavior (Weinstein and Pinciotti 1988). Furthermore, in a seminal study in Great Britain, Titman (1994) found that the conditions of and care put into schoolyards, the "Hidden Curriculum", influenced students' behavior and feelings of self-worth, suggesting that the conditions of the entire schoolyard, not just the play spaces, can affect students' wellbeing.

As early as the 1970s it was argued that the addition of greenspaces on yards had the potential to rectify some of the design failures of the urban schoolyard and benefit student development and mental health. Moore (1974) argued that natural elements provide considerable complexity and diversity in play spaces: they offer multiple and varied sensory experiences and can be readily modified and experimented with. Furthermore, in his interviews with schoolchildren, natural spaces were the most commonly desired and coveted schoolyard elements. The work of Moore and others has inspired the 'schoolyard habitat' and 'outdoor classrooms' movements, which support the development of natural spaces on yards as well as outdoor curriculum that reconnects urban children to the natural environment (see Rivkin 1995, Rivkn 1997). Until recently, however, few studies existed that directly and quantitatively demonstrated the benefits of greenspace. Now a growing body of literature examining the impacts of urban greenspace, especially urban trees, provides strong support for the argument that the inclusion of vegetation on city schoolyards would provide valuable benefits to students, both in terms of healthy development and behavior, as well as environmental quality and health. The following briefly reviews these findings.

Greenspace, psychological development, and behavior

In what is likely the first controlled study of greenspace's impact on play, Taylor et al. (1998) observed children's activities in different courtyards within the same Chicago public housing development, where the only variable was the amount of vegetation-predominately trees-present. Vegetation levels varied from sites with no greenspace to those that were almost 100% tree canopy (F. E. Kuo, University of Illinois at Urbana-Champaign, written communication, September 8, 2006). The authors found that children in areas with relatively high levels of vegetation (levels above the overall median value) engaged in twice as much play, and also more creative play than children in areas with low levels of vegetation. In another study, Taylor et al. (2001) found that urban greenspace in play areas helped children afflicted with attention deficit disorder (ADD) cope with their ADD.

Simply the presence of natural settings and views has been found to promote healthy behavior among children. For example, inner city children who had views of dense vegetation from inside their home performed measurably better on tests of self-discipline than those with little to no visible vegetation (Taylor et al. 2001). Furthermore, a study of aggression and vegetation in the inner city found that high levels of vegetation decreased aggression, most likely by reducing mental fatigue (Kuo and Sullivan 2001). Although this study focused on urban adults, it is likely applicable to children and supports observations made by Moore (1989) and Weinstein and Pinciotti (1988) that the presence of greenspace reduces aggressive tendencies among youth.

Greenspace and urban environmental quality

The potential to improve local environmental quality has received little focus from those who advocate for natural elements on schoolyards. However, recent research on urban greenspace suggests vegetation is essential for the environmental health of cities and neighborhoods. Collectively termed the *urban forest*, urban vegetation, particularly city trees, can mitigate the urban heat island (Taha 1997; Taha et al. 1997), reduce urban runoff and nonpoint source pollution (Xaio 1998; Paul and Meyer 2001) and sequester air pollutants (Taha et al. 1997; Raza et al. 1990). Impacts are also apparent at small scales. For example, at the local-scale (a neighborhood or park) and micro-scale (a block, building, or schoolyard), vegetation moderates climate in the summer. The "oasis effect" produced by vegetated urban sites is well documented: a review by Taha et al. (1997) found that vegetated city spaces could be 2–8°C cooler than their surroundings. At these scales, urban trees also reduce air pollution, and are an essential part of design strategies for improving ground-level air quality (Spirn 2003). Researchers have even begun to attach a dollar value to the environmental benefits the urban forest provides. In 1991, trees in Chicago's urban forest were valued at $402 each for their environmental services (McPherson et al. 1997).

In recognition of the environmental quality benefits of the urban forest, a number of cities and urban forestry organizations have begun to establish goals for percent tree canopy cover in urban areas. For example, in a study sponsored by the USDA Forest Service, American Forests, the national conservation organization, established tree canopy goals for U.S. cities (American Forests 1999). For cities east of the Mississippi, these goals are: 40% cover overall, 50% for suburban residential, and 25% for urban residential. Baltimore is one of the first cities to adopt this recommendation (Doebber, personal communication).

What is the state of the public urban schoolyard?

Considering the findings related above, as well as the fact that children spend nearly a third of their day on school property, schoolyards represent key spaces for providing quantities of greenspace that support healthy physical and emotional development. Although the "prison schoolyard" anecdote remains in active use (Heffeman 1994), little is known about the actual structure of schoolyard landcover in U.S. cities.

In this study we investigated the landcover of public urban schoolyards in three major U.S. cities, Baltimore, MD., Boston, MA., and Detroit, MI., with a particular focus on vegetation and tree canopy cover. Geographic Information System software was used to analyze random samples of public elementary and middle schools within these cities. Four research questions were addressed: In terms of size and landcover, what is the structure of urban schoolyards in the three cities? How does school cover vary within and between these cities? Is there a relationship between schoolyard size and landcover structure? And, are schoolyards in the three cities providing healthy amounts of vegetation and trees, based on benchmarks such as those established by American Forests, or are they indeed asphalt deserts? Based on our findings and the work of several U.S. greening initiatives, we end by discussing obstacles to greening as well as what might be done to transform barren schoolyard landscapes in these cities and others to greener, healthier and more productive ones.

Methodology

Study areas

Three U.S. cities were chosen as study sites, Baltimore, MD., Boston, MA., and Detroit, MI (Table 1). Boston and Baltimore are both cities where schoolyard rejuvenation initiatives, of varying scales, are currently taking place. In both cases, analyses for this study were based on data collected *before* Baltimore and Boston's schoolyard programs were initiated. Thus this landcover analysis provides comparative data against which changes can be measured; this is particularly true for Boston, where over 60 schoolyards have been reconstructed since 1995. Detroit has no developed schoolyard initiative. It is geographically and demographically quite different from the two northeastern cities; its inclusion allowed for a more comprehensive investigation into schoolyard cover.

Only public elementary schools and middle schools were analyzed. High schools, which often include large, grass sports fields, were not sampled so as not to confound the landcover data. Private schools were not sampled. A complete data set of classified Baltimore schools from the year 2000 was provided by Parks and People, a Baltimore open space advocacy group. 139 middle and elementary schools from the Baltimore City Public School system, serving nearly 100,000 students, were sampled. A random sample of 75 schools was selected out of the 95 elementary and middle schools in the Boston School System, which serves nearly 60,000 students. From the Detroit School System, which serves over 165,000 students, 44 schools were randomly selected from 249 elementary and middle schools in the system. Due to data constraints, this sample was smaller and represented a smaller percentage of the total population than the other two samples. To ensure that the sample was representative, we used stratified random sampling: The Detroit region was divided into four equal sized quadrants, containing similar numbers of schools (N=51, 53, 58, 66). From each quadrant, 11 schools were randomly sampled. The average property size of the Detroit sample was also compared against the average property size for all the elementary and middle schools in Detroit and found to be representative: 2.5 vs 2.6 ha, respectively.

Table 1 Study cities' geographic and demographic statistics

	Area (mile^2)	Population (1,000s)	Density (persons/mile^2)	Median income	Urban forest canopy cover[a] (%)	Approximate hectares of parkland	No. of public elementary and middle schools[b]
Baltimore	80	650	8,058	$30,000	25	2,400	139
Boston	48	590	12,165	$39,000	22	900	95
Detroit	139	951	6,855	$29,000	31	2,400	249

[a] Canopy values provided by the National Forest Service UFORE studies and American Forest CITYgreen analyses (American Forests 1999, 2006)

[b] These numbers are subject to annual change and represent the number of schools at the time of the study

School property classification

Aerial photographs, made available from public and private sources, were used to produce schoolyard landcover data sets for Boston and Detroit. (As mentioned, a landcover data set for Baltimore was found to be in existence). Half meter per pixel, black and white aerial photographs of Boston, circa 1995, were downloaded from the State of Massachusetts' "MassGis" website, and geo-referenced for Boston's elementary and middle schools. Six inch per pixel, black and white aerial photographs of Detroit, circa 1999, geo-referenced for all the Detroit public schools, were made available through the Office of Student Transportation, Detroit. Photo images used to classify Baltimore and Boston were taken before each city's respective rejuvenation initiative.

The ESRI distributed GIS software ArcView was used to delineate and classify the schools. The property boundaries for the Boston schools were digitized manually using land parcel information provided by the city of Boston's web-based "Boston Atlas". Property boundaries for Detroit were also made available via the Office of Student Transportation. To facilitate comparative analyses among cities, Baltimore's classification system was used for all three cities, with one minor modification: instead of grouping all impervious surface into one category (as the Baltimore system does), light impervious surface cover (ISC) was separated from asphalt (dark ISC):

1. Structures (buildings)
2. Coarse vegetation (trees or shrubs with crowns >2 m)
3. Fine vegetation (small shrubs <2 m and grasses)
4. Asphalt
5. Other (impervious surfaces: cements, light colored materials, etc.)

The decision to separate ISC into two categories was based on the fact that in hot weather, a yard paved with asphalt would create a much warmer and potentially more stressful environment than a yard covered in light colored ISC. However, in comparing significance levels between the cities, the Baltimore system was used for all three cities (i.e. "asphalt" and "other" were combined to yield "ISC").

As defined in the introduction, schoolyard refers to all the school property that is non-building. Thus, class 1 (building) is the only non-yard cover type and classes 2–5 make up the schoolyard. All classification and digitization was done manually (see Fig. 1). Classification decisions were double-checked against a second set of color photos, of the same year, made public online by each state.

Schoolyard landcover analyses within and between cities

Once school properties were classified, landcover areas were normalized by the schoolyard area to yield percent cover values. In this way, comparisons could be made across schoolyards of different sizes. The statistical software SPSS 10.0 was used to calculate all statistics (SPSS Inc. 2000). Descriptive statistics, such as, mean, standard deviation, maximum, and minimum values, were calculated for landcover types on the school properties and yards in each city.

Within each city, we were also interested in examining the relationship between schoolyard size and schoolyard landcover types: ISC, fine vegetation, and coarse vegetation. To examine if there was a statistically significant association between schoolyard size and the percent cover of different landcover types in each city, a correlation

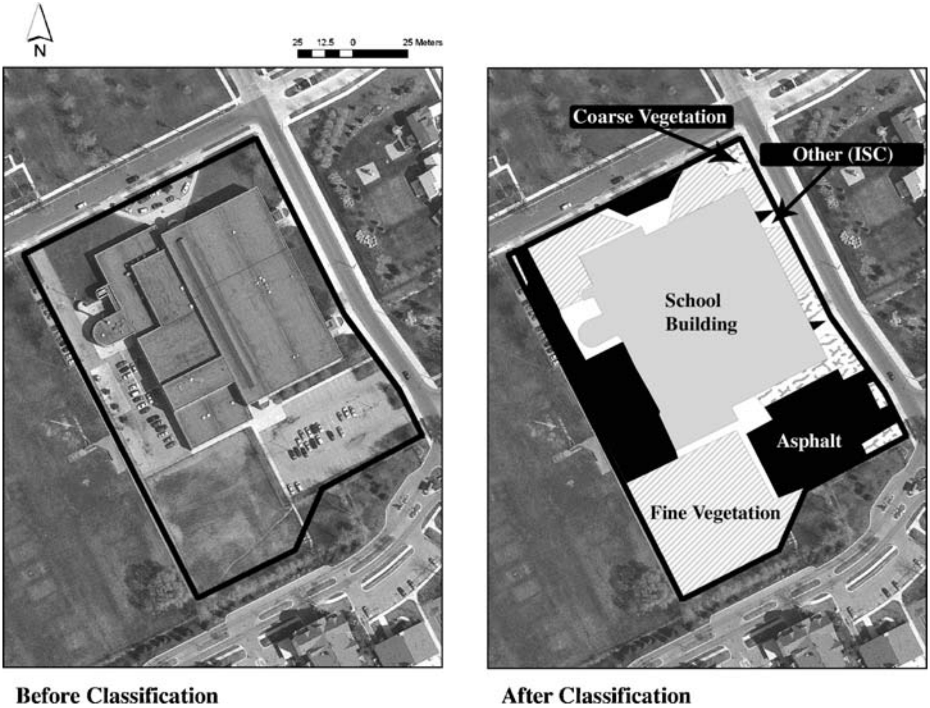

Fig. 1 Robinson Middle School in Detroit, MI is shown in aerial imagery with property boundaries outlined in *black* (*left*). It is shown again (*right*) after the property landcover was digitized

(two-tailed) was computed. As the samples were not normal, the Spearman's rho statistic was used and significance at the 0.05 level was calculated.

To examine the differences in school property and schoolyard landcover quantities across the cities, we ran two ANOVAs. The first ANOVA compared differences in the mean quantities of school property and cover types, measured in hectares. The second ANOVA was used to look at the structure of the average schoolyard in each city, and analyzed whether there were statistically significant differences in the mean percent cover of ISC, fine vegetation, and coarse vegetation across the three cities. Given the samples' violation of normality and homogeneity of variance, the conservative Tamhane's T^2 test, measuring significance at the 0.05 level, was used for the post-hoc multiple comparison (Tamhane 1979). We recognize that although the ANOVA is typically robust to violations of its assumptions, uneven sample sizes combined with the violation of homogeneity can potentially produce incorrect p values. However, in the absence of a more robust statistic, we proceeded with the Tamhane's T^2.

Results

School property and landcover area

School properties and landcover area varied by many hectares within and between the three cities (Table 2). School property sizes ranged from minimums of less than one hectare to maximums of 14.65, 5.77, and 17.51 ha in Baltimore, Boston, and Detroit, respectively.

Schoolyard area in each city had a range similar to that of the school property area. However, school building footprints showed less variation, ranging from under half a hectare to approximately 2 ha. In all three cities, the minimum area of coarse vegetation found on a schoolyard was 0.00 ha. The minimum area of fine vegetation was also 0.00 ha in Baltimore and Boston, and 0.07 ha in Detroit. Impervious surface cover, was present on every school in all three cities, with minimum values of 0.01, 0.08, and 0.05 ha in Baltimore, Boston, and Detroit, respectively. However, the most impervious surface on any school was 3.00 ha (in Baltimore), whereas the most maximum values for vegetation and coarse vegetation were higher, at 8.50 ha (in Baltimore) and 8.30 ha (in Detroit), respectively.

Detroit and Baltimore showed many similarities in property and landcover sizes, and schools in these cities were, on average, nearly two times larger than those in Boston. The results of the Tamhane's T^2 analysis of variance found no statistically significant difference (measured at the $p<0.05$ level) between the mean area values in Baltimore and Detroit (see Table 2). However, mean area values in Boston were found to be significantly different from both Baltimore and Detroit in all classes except coarse vegetation.

Schoolyard landcover: Percent cover values and greenspace

In all three cities, the average school property area was more than 50% schoolyard (i.e. non-building). The mean percentage of school property area that was schoolyard was 72.02%, 68.23%, and 78.62% in Baltimore, Boston, and Detroit, respectively (Fig. 2).

Boston was found to have the highest mean percent ISC cover on its schoolyards (Fig. 3). The average schoolyard in Boston was 60% asphalt and over 70% ISC. Baltimore

Table 2 Maximum, minimum, and mean hectares (ha) of school property and school landcover in Baltimore, Boston, and Detroit

	City	Number of sampled schools	Minimum (ha)	Maximum (ha)	Mean (ha)	SD
School property	Baltimore	139	0.08	14.65	2.24A	2.22
	Boston	75	0.19	5.77	0.94B	0.88
	Detroit	44	0.65	17.51	2.55A	2.66
School building (footprint)	Baltimore	139	0.02	1.89	0.45A	0.31
	Boston	75	0.06	1.02	0.28B	0.22
	Detroit	44	0.11	1.34	0.45A	0.27
Schoolyard	Baltimore	139	0.04	13.16	1.79A	2.00
	Boston	75	0.11	5.05	0.66B	0.72
	Detroit	44	0.37	16.56	2.10A	2.51
Coarse vegetation	Baltimore	139	0.00	2.07	0.20A	0.35
	Boston	75	0.00	2.04	0.09B	0.27
	Detroit	44	0.00	8.34	0.39AB	1.24
Fine vegetation	Baltimore	139	0.00	8.50	0.95A	1.38
	Boston	75	0.00	2.02	0.17B	0.29
	Detroit	44	0.07	7.64	1.15A	1.31
Impervious surface	Baltimore	139	0.01	3.00	0.64A	0.51
	Boston	75	0.08	1.42	0.40B	0.27
	Detroit	44	0.05	1.73	0.56A	0.34

Means followed by the same letter do not differ from one another according to Tamhane's T^2 multiple comparison analysis with significance measured at the 0.05 level

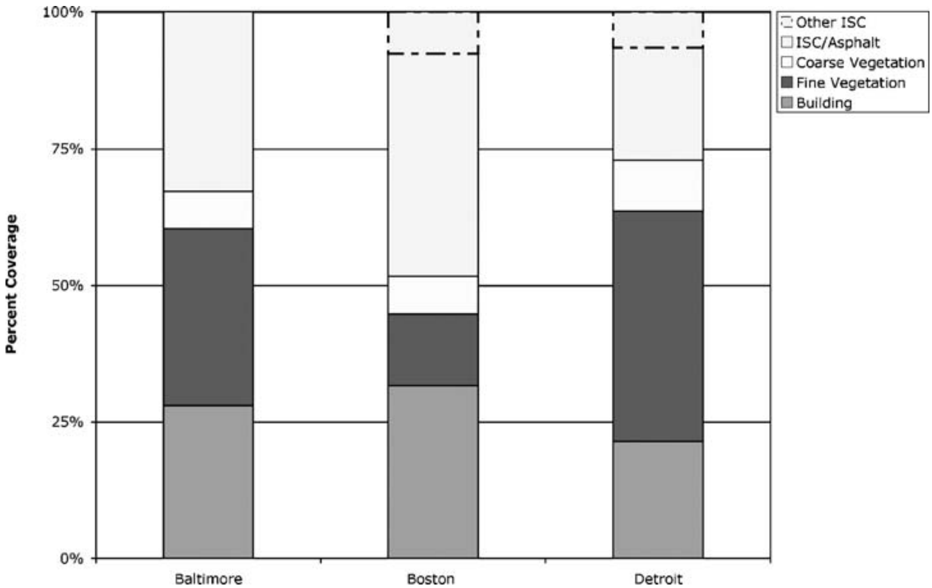

Fig. 2 The average school property in Baltimore was found to be 27.987% building, 32.26% fine vegetation, 6.75% coarse vegetation, and 33.01% ISC. In Boston, it was 31.77% building, 13.10% fine vegetation, 7.00% coarse vegetation, 40.81% asphalt, and 7.32% light colored ISC. In Detroit, it was 21.38% building, 42.09% fine vegetation, 9.30% coarse vegetation, 20.62% asphalt, and 6.61% light colored ISC

yards were on average nearly 50% ISC, while more than 50% of the average schoolyard in Detroit was composed fine vegetation (lawn). In all three cities, coarse vegetation (tree canopy) was the smallest mean fraction of schoolyard cover. The highest mean percent schoolyard cover of coarse vegetation (11.80%) was found in Detroit. An ANOVA found the percent of coarse vegetation on the schoolyards to be the only schoolyard landcover class that was not significantly different across the three cities (Fig. 3).

In each city maximum values of coarse and fine vegetation cover were often higher than those of ISC. However, the minimum values of ISC remained above 0, while fine and coarse vegetation were often lacking from schoolyards (Table 3). Of the three cities, Boston had the largest number of schoolyards with little to no coarse or fine vegetation. Of the 75 schoolyards sampled, 24% (18 schools) had no fine vegetation, 28% (21 schools) had no coarse vegetation, and 11% (8 schools) had no greenspace at all (neither coarse nor fine vegetation). In all three cities, a majority of the schoolyards had less than 10% cover of coarse vegetation.

Schoolyard size and landcover correlation

For all three cities, the results of the Spearman's rho correlation analysis found significant correlations ($p<0.05$) between the percent cover of ISC and fine vegetation with schoolyard size (Table 3). In all cities, the direction of correlation for percent cover of ISC and schoolyard size was negative and significant at the 0.05 level. Thus, in all three cities, larger schoolyards tended to have less percent cover of impervious surface and vice versa. Baltimore showed the strongest negative relationship between ISC and schoolyard size, $r_s(137)=-0.699$, $p<.001$.

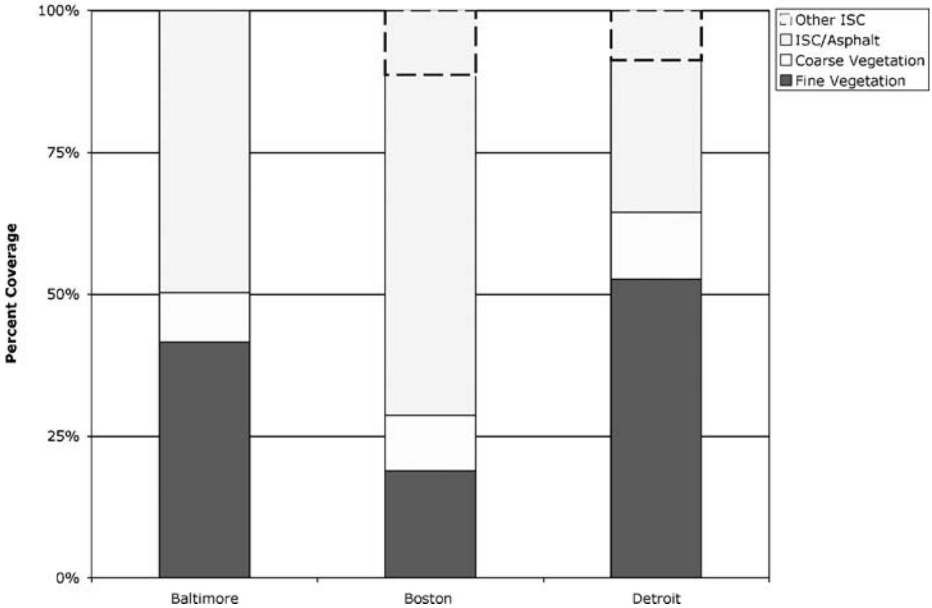

Fig. 3 The average schoolyard in Baltimore was found to be 41.47% fine vegetation, 8.68% coarse vegetation, and 49.85% ISC. In Boston, it was 18.82% fine vegetation, 9.84% coarse vegetation, 60.00% asphalt, and 11.34% light colored ISC. In Detroit, it was 52.60% fine vegetation, 11.80% coarse vegetation, 26.83% asphalt, and 8.77% light colored ISC. A Tamhane's T2 multiple comparison test found all three cities to have statistically significant different means in the percent schoolyard cover of fine vegetation and ISC ($p<0.05$). In the class of coarse vegetation, an ANOVA found no significant difference was found between the cities ($F=1.51$, $p=0.222$)

However, in all three cities the relationship between the percent cover of fine vegetative and schoolyard size was positive and significant at the 0.05 level, meaning that larger yards tended to have higher percent cover of lawn and vice versa. In the case of coarse vegetation, there was no significant relationship between schoolyard size and tree cover in Boston or Detroit. In Baltimore, a significant positive correlation was found: $r_s(137)=0.531$, $p<0.001$ (Table 4).

Discussion

Greenspace, and the schoolyard

The results of the schoolyard analysis show that schoolyards in the three study cities are composed primarily of fine vegetation and ISC (the majority being asphalt), with little tree cover. This result returns us to one of the primary questions of this study: are schoolyards in the study cities indeed asphalt deserts or are they providing adequate greenspace? Boston schoolyards (circa 1995) appear to be the epitome of the asphalt desert, with their very high levels of ISC and low levels of greenspace. In 1995, nearly 30% of Boston schoolyards had no tree cover, and over 10% had no greenspace at all. As in the other two cities, the average Boston schoolyard had 10% tree cover. How adequate is this amount? By all standards, it is very low and inadequate. One measure of its inadequacy is derived from the behavioral

Table 3 Number/percentage of schoolyards sampled in Baltimore, Boston, and Detroit with less than 10%, 5% or 0% of coarse and fine vegetation cover

Cover type(s)	City	Yards with under 10% of (each) cover type		Yards with under 5% of (each) cover type		Yards with 0% of (each) cover type	
		Number	Percentage	Number	Percentage	Number	Percentage
Fine vegetation	Baltimore (*N*=139)	15	11	11	8	4	3
	Boston (*N*=75)	26	35	23	31	18	24
	Detroit (*N*=44)	1	23	0	0	0	0
Coarse vegetation	Baltimore (*N*=139)	95	68	74	53	27	19
	Boston (*N*=75)	46	61	29	39	21	28
	Detroit (*N*=44)	24	54	14	32	1	2
Fine and coarse vegetation	Baltimore (*N*=139)	15	11	11	8	4	3
	Boston (*N*=75)	15	20	11	15	8	11
	Detroit (*N*=44)	0	0	0	0	0	0

For example, in the class of fine vegetation, 15 schoolyards in Baltimore had under 10% cover of fine vegetation or 11% (15/139=11%) of the schoolyards sampled had under 10% cover fine vegetation Percentages are rounded to the nearest whole number

studies of Taylor et al. (1998) and Kuo and Sullivan (2001). Although the authors' greenness rating was not based on percent cover, in both study sites with 10% tree cover would have been classified as having 'low' levels of greenspace (Sullivan, personal communication). Another measure is derived from environmental quality standards. For example, American Forests has established a 25% canopy cover goal for urban residential areas, 50% for suburban residential, and 40% overall for cities east of the Mississippi. Sub-10% cover is lower than either cover goal, and is the same level American Forest recommends for urban industrial sites (American Forests 1999) Furthermore, it seems reasonable to expect that green yards should provide canopy cover levels at least as high or higher than those of the surrounding city (see Table 1). Using this standard, the majority of yards in all three cities again fail to provide sufficient levels of tree cover.

Although the amount of tree cover is low, when the fine vegetation is considered, the average yard in Baltimore and Detroit is 50% or more greenspace. Thus, most schools in these cities do not actually fit the 'asphalt desert' characterization. Lawns can provide environmental benefits, such as local cooling (Arnfield 2003), however, lawns on schoolyards are typically used for recreation (such as field sports) and may not be well maintained or irrigated, as found by a Boston schoolyard taskforce (Boston Schoolyard Initiative 2001). Lawn wear is common and soil compaction is likely. Compacted soils show similar properties to impervious surfaces (Gregory et al. 2006), and would provide few environmental quality benefits. Furthermore, as mentioned, the behavioral literature has focused on spaces in which tree cover forms the majority of greenspace. The behavioral value of lawn, on its own, remains unstudied. In these respects, it is unlikely that high levels of lawn produce behavioral and environmental benefits comparable to those conferred by similar levels of tree cover.

Opportunities and obstacles to greening

The findings of this study show that public schoolyards in the three cities are lacking in healthy levels of greenspace, specifically tree cover. More optimistically, the findings also reveal a vast

Table 4 Correlation of schoolyard size and percent cover of ISC, fine vegetation, and coarse vegetation in Baltimore, Boston, and Detroit

Spearman's rho		% ISC	% Fine vegetation	% Coarse vegetation
Baltimore schoolyard size (ha)	Correlation coefficient	−0.699[a]	0.637[a]	0.531[a]
	Significance (two-tailed)	0.000	0.000	0.000
Boston schoolyard size (ha)	Correlation coefficient	−0.515[a]	0.524[a]	0.148
	Significance (two-tailed)	0.000	0.000	0.205
Detroit schoolyard size (ha)	Correlation coefficient	−0.505[a]	0.307[a]	0.194
	Significance (two-tailed)	0.000	0.042	0.206

[a] Correlation is significant at the 0.05 level (two-tailed)

opportunity to expand the amount of urban greenspace and communities' and children's access to it. Schoolyards, on average, make up 68% or more of the school property in all three cities. If we use the average schoolyard size in each city to estimate how much schoolyard acreage exists in the three cities—based on the total number of schools in the public school system—we find that in Baltimore, there are approximately 327 ha of schoolyard. In Boston and Detroit there are approximately 86 ha and 787 ha of schoolyard, respectively, this is probably an underestimate given that high schools are larger than elementary and middle schools. In Baltimore, Boston, and Detroit, schoolyard takes up approximately 1.6%, 0.6%, and 0.9%, respectively, of each city's total area. If 40% canopy coverage were achieved on the schoolyards in Baltimore, Boston, and Detroit, schoolyards in the three cities would account for 130, 34, and 314 ha of urban forest canopy. In the overall context of the city, this amount is relatively insignificant, and is dwarfed by each city's hectares of parkland (see Table 1). However, unlike most parkland, these hectares would be distributed in hundreds of small packages, throughout the city, providing greenspace for students and communities in heavily developed areas. Thus, tree cover and overall greenspace augmentation on schoolyards could improve student behavior and local environmental quality, and could function as "pocket parks," an urban greenspace model that has been implemented (though not using schoolyards) in Jacksonville, FL, as well as overseas in Hampshire and other parts of the United Kingdom.

In order to move towards a model of green schools, it is important to understand potential obstacles and limitations to greening. While the myriad variables that influence landcover and design of yards should not be discounted, the results of this study suggest that schoolyard size may be one important influencer, as this study showed that larger schoolyards were correlated with lower levels of ISC and higher levels of fine vegetation. It is probable that the fact that Boston schoolyards were smaller than those in Baltimore and Detroit, accounts for their having more ISC coverage on average. It makes sense that there is some minimum amount of ISC required on schoolyards, for parking, walkways, and certain recreation, which suggests that smaller schools may have more difficulty increasing levels of schoolyard greenspace than larger schools.

However, unlike vegetation, the percentage of tree cover was not—or only very weakly—correlated with schoolyard size. Furthermore, it was the only landcover type that showed no significant difference in percent cover across the three cities. How might this be explained?

One way to understand the levels of tree canopy on schoolyards is to see it as a reflection of historic circumstances as well as perceptions of the schoolyard's utility. For example, in the 1950s, many new Baltimore schools were sited on razed residential land plots, and it was considered easier to pave over the area than develop a yard design (Doebber, personal communication). Furthermore, throughout time, schoolyards have been viewed primarily as areas for exercise. After the first Olympics in1896, the gymnasium and physical education made their appearances in schools (Graves 1993) and recess began to be viewed by adults as an opportunity to direct the energy of children for physical benefits. This became especially true during the First World War, when many poor city youth did not meet the basic physical requirements for entering military duty. Funds were directed towards the creation of public playgrounds that would enhance their fitness and motor skills (Hendricks 2001). The design of these playgrounds was usually limited to the installation of equipment that, in a somewhat evolved form, still dominate American public schoolyards: swings, see-saws, slides, and jungle-gyms, all set in cement. As Frost and Klein (1979) have noted sardonically about the construction of the American school playground:

> As soon as the natural terrain is destroyed, the 'concrete mentality' takes over. Someone is reminded that a school is being built and that children attend schools. So vast areas are covered with asphalt and/or concrete and marked off into ball courts... Children can do what they are supposed to do—build strong healthy bodies and provide good material for the high-school athletic teams.

These ideas about the utility of outdoor space on school properties may also explain the dominance of schoolyard lawn, which can be used for organized sports. The inclusion of trees on yards has likely come as an aesthetic after thought, resulting in low overall cover on most urban yards.

However, given the interest in greening yards and changing perceptions about schoolyard utility, history cannot be entirely at fault for yards' current state. There are also a number of other obstacles to enhancing tree cover on yards that must be addressed in any greening program. One of the most obvious and important restrictions is funding. School budgets are notoriously tight, and tree planting and maintenance can be a costly endeavor (McPherson et al. 2005). Paving, particularly asphalt, has been considered the landcover of least maintenance and most utility among many school districts (Rodgers, personal communication). Another concern regards security. Although security is a priority of all schools, it is especially important for inner-city ones. Thus schoolyards are often designed to be "vandal proof" (Wolff, personal communication). Although recent studies suggest that levels of greenspace and neighborhood crime may be inversely related (Kuo and Sullivan 2001), many communities and school administrations fear that vegetation on schoolyards will promote criminal behavior by providing concealed regions in the yard (Wolff, personal communication). This has resulted in schoolyards that are flattened and stripped of any obstruction or niche, including trees and shrubs. Finally, with increases in litigation related to schoolyard accidents, a "criminalization of natural play" has occurred (Louv 2005). Unlike standard and approved play equipment, natural materials are unpredictable and raise fears that they will precipitate injuries and lawsuits.

Lessons from schoolyard initiatives

Fortunately, a number of schoolyard initiatives, two of which are in Baltimore and Boston, provide potential models for how obstacles to greening can be overcome. The Boston Schoolyard Initiative (BSI) is recognized as a trailblazer in inner-city schoolyard redesign, though it is not explicitly dedicated to greening. BSI was formed in 1995, when a land-use task force found the city's yards to be a "appallingly neglected patchwork of broken pavements, torn fences, compacted soil and hazardous play equipment" (indeed, this is the condition recorded in this study, which used pre-initiative landcover data), and spurred local and government action (Boston Schoolyard Initiative 2001). Since then, over 60 schoolyards have been reconstructed. BSI presents one model for overcoming one of the most daunting barriers to schoolyard greening: a dearth of capital funds. BSI is supported through a public–private partnership. Each Boston schoolyard re-design runs approximately \$250,000 in capital expenses (design and construction) and is underwritten by the City of Boston as part of its annual budget. The Boston Schoolyard Funders Collaborative (BSFC) is the private half of this funding arrangement. The BSFC manages private sector involvement and is primarily responsible for awarding small grants for continuing work on schoolyards.

In a funding arrangement that may be more appropriate for greening initiatives, several other cities have leveraged urban environmental quality concerns and legislation to acquire financial support for schoolyard greening. For example, Baltimore's Department of Public Works, in partnership with a number of local organizations including the not-for-profit Parks and People, is currently complying with runoff and water quality legislation by using capital improvement funds to remove asphalt from schoolyards and add vegetation. In another unique arrangement, some Baltimore developers have been removing hectares of asphalt from schoolyards to meet their development mitigation requirements. Under Maryland's critical area law (created to protect the Chesapeake Bay's water quality), developers are required to mitigate 20% of their development impact, and beginning in 2002, several Baltimore developers who were unable to mitigate on site were permitted to do so offsite, through the removal of impervious surface on some of Baltimore's larger and mostly asphalt schoolyards. On one of those schoolyards, nearly 1.5 ha of asphalt was removed. The capital expenses for all these projects are similar to those in Boston (approximately \$250,000). Nine schoolyards have been greened through these partnerships, and six more are in the works (Doebber, personal communication).

A similar funding arrangement was developed in Los Angeles, where the Department of Water and Power sponsored the Cool Schools Program in 1998. The program was initiated to remove asphalt and increase greenspace on schoolyards, thereby decreasing stormwater runoff, providing local cooling, and reducing school energy bills. Permeable surfaces were increased and over 4,000 trees were planted at 40 district schools (Longcore et al., unpublished paper).

The organization and design process of a greening program is also important. Boston's initiative is an excellent example of strong organization and a well-structured and streamlined process. As an organization, BSI is wholly dedicated to schoolyard re-design and thus can operate more efficiently and comprehensively than can a non-profit for whom schoolyard greening is only one of its programs (Boston Schoolyard Initiative 2001). BSI has also developed a highly inclusive and structured community design process: members of the local community work with government officials and professional landscape architects to create schoolyard designs that fulfill student and community needs, inculcate shared ownership and commitment, ensure sustained maintenance, and address unique community concerns (Meyer, personal communication). The many community meetings and design sessions, facilitated by a community organizer, also allows issues such as safety and security concerns to be aired and addressed in the yard design.

The behavioral impacts of these initiatives are understudied and largely anecdotal. However, several studies have measured the increase of greenspace and environmental quality impacts resulting from schoolyard initiatives. Using design plans and pre-construction imagery, a preliminary study of ten redesigned Boston schoolyards found that greenspace—a mixture of coarse and fine vegetation—was added on nine out of ten schools (Schulman 2004). The same study found that the average greenspace cover increased from 30% to

43%, a 13% increase. It is not clear how much tree canopy increased across all the yards, and no studies have been done that calculate the citywide increase in yard tree canopy or greenspace. Studies on the environmental quality impacts of yard greening have been undertaken in Los Angeles, through the University of Southern California Sustainable Cities Program. They used CITYgreen, software developed by American Forests, to model the change in greenspace and environmental quality impacts on ten schoolyards from its Cool Schools program (Longcore et al., unpublished paper). The study found that over 10 years (when the planted trees matured): the average tree canopy on the schoolyards would increase from 9% to 20%; water retention would be improved by 97%; and air pollution sequestration would double. This type of study could be applied in Boston, Baltimore, as well Detroit.

Recommendations

Given the results of this study, we make the following recommendations. These recommendations apply to the three study cities, the greening programs in Baltimore and Boston, as well as other cities interested in, or currently developing, a schoolyard greening program.

Increase tree canopy in the three study cities This study found that many schoolyards in Baltimore, Boston, and Detroit, while not necessarily asphalt deserts, have very low levels of schoolyard tree cover (an average of 10%). Such levels should be increased. Although Baltimore and Boston have schoolyard initiatives, these cities should develop and integrate canopy cover goals into future schoolyard design plans. As Baltimore's program is relatively young, it would be particularly useful for it to develop canopy cover goals now that can be applied to the design of future schools. Of course, such goals should be locally appropriate and sustainable. We recognize that there is a need for some hardscape on yards; that it may be more difficult for small yards to attain high canopy cover; and that good landscape designs require far more nuance than a canopy cover standard. However, designs should take into consideration the tree cover recommendations of organizations such as American Forests and findings of the environmental behaviorists discussed here.

Take advantage of GIS and modeling software in planning for and studying the impacts of schoolyard greening It is probable that other cities, in addition to the ones studied here, have low levels of greenspace and tree cover on their yards. The GIS analysis presented in this study could easily be applied in other cities that are interested in greening, and could assist in prioritizing sites (as not all sites need greening). Furthermore, as seen in Los Angeles, GIS based software, such as American Forests' CITYgreen program or the Forest Services Urban Forests Effect (UFORE) model, can be used to produce useful models of environmental quality improvement, and possibly leverage environmental quality related funding.

Increase studies on the impacts of greening There is a need for more quantitative studies of schoolyard greening. Initiatives in Baltimore and Boston, and other cities with similar programs, would benefit themselves and others by studying, modeling and making publicly available the impacts of the landcover changes on behavior and environmental quality. This study has shown that, before their respective initiatives, greenspace and tree cover on schools in Baltimore and Boston was unacceptably low, but by how much have the initiatives changed that? Results of these studies could be used to leverage additional funding, assist in the development of canopy cover goals, improve the understanding of greenspace's impacts on child behavior, as well as provide information to other cities that are contemplating schoolyard greening. For Baltimore, Boston, and Detroit, this study provides one baseline against which changes can be measured.

Some studies could be undertaken by the school children themselves and integrated into the school curriculum. Particularly for older students, there are numerous educational opportunities for learning through the greening process, and not only through its outcomes. For example, students could use GIS software or CITYgreen to develop a schoolyard design with desired environmental impacts. A study of the environmental effects of greening, such as changes in schoolyard surface temperature or energy use in the school building would make for extremely pertinent science and math projects. In this way, greening projects might provide desirable greenspace and also serve as tools to help students develop urban environmental stewardship skills that they can carry with them into their adult lives.

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