Urban Vegetative Cover Fragmentation in the U.S.

Associations with Physical Activity and BMI

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Introduction: Urban vegetative cover provides a range of ecosystem services including contributions to human health and well-being. Urbanization exerts tremendous pressure on this natural resource, causing fragmentation and loss of urban greenspace. This study aimed to examine associations between vegetative cover fragmentation and physical activity and BMI at the county scale in the U.S. metropolitan statistical areas greater than 1 million in population.

Methods: National Land Cover Database 2006 and Behavioral Risk Factor Surveillance System 2008 provided land cover and human health data, respectively. Analyses were performed in 2013 at the county scale where the health data were reported. Spearman rank correlation and stepwise and hierarchical regression models were applied to estimate relationships between land cover and health variables.

Results: After controlling for median household income and race, greater forest edge density ($\beta=0.272, p<0.05$) and larger size of herbaceous patches ($\beta=0.261, p<0.01$) were associated with higher percentage of participation in physical activity within counties. More connections between forest and developed area ($\beta=0.37, p <0.01$) and greater edge density of shrubland ($\beta=0.646, p<0.001$) were positively associated with higher percentage of normal BMI ($<25 \text{ kg/m}^2$) within counties.

Conclusions: Forest land cover and some degree of fragmentation are associated with population physical activity. Future studies should examine how built environments and varying land cover configurations influence physical activity and weight status.

Introduction

Physical inactivity and obesity remain important public health challenges. In the U.S. and many industrialized countries, most adults do not accumulate sufficient physical activity, increasing their risk for overweight, cardiovascular diseases, some forms of cancers, reduced bone strength, and mental disorders.^{1,2} Public parks and greenspace have become more prominent among environmental and policy strategies to increase physical activity and prevent obesity.³ Thus, loss or significant alteration of urban greenspace can have important consequences for public health. More than 80% of the U.S. population lives in urban areas. Between 2000 and 2010, the urban population in the U.S. grew by 12.1%, ahead of overall population growth of 9.7%.⁴ Because of expanding urbanization, tremendous pressure is exerted on natural ecosystems, leading to landscape fragmentation and loss of greenspace and open space available for outdoor recreation and physical activity.^{5,6} It is imperative to understand relationships of urbanization and urban vegetation fragmentation on public health as more of the world's population lives in urbanized areas.

Multiple studies document how parks and public greenspace support recreation and physical activity among adults and children.⁷⁻¹⁰ Natural features such as trees, water,¹¹ greenspace in neighborhoods,^{12,13} and greenness along greenway trails¹⁴ are associated with greater use¹⁵ or enhanced enjoyment of such resources. Longitudinal evidence suggests that urban greenspace has also been linked to weight status among children,¹⁶ although the findings may be restricted in highly populated areas.¹⁷ Adjusting for SES covariates, Lovasi et al.¹⁸ observed that higher street tree density was associated with a 12% lower prevalence of obesity among children (aged 3–5 years) in New York City. By contrast, Potestio and colleagues¹⁹ found marginal or no significant associations between several objective measures of greenspace in Calgary and children's weight

status after adjusting for SES. Among adults, lower BMI has been observed in high greenspace (measured by normalized difference vegetation index) neighborhoods with more destinations for walking than in less green neighborhoods.²⁰ Ellaway et al.²¹ used trained auditors to obtain measures of local vegetation in eight European cities. This study found that residents of areas with a high greenery level were significantly less likely to be overweight or obese (measured by BMI).

Although evidence on contributions of urban natural greenspace to physical activity and healthy weight status is accumulating, opportunities exist to extend the literature in significant ways. First, most studies involving greenspace and physical activity and obesity are conducted at the park or neighborhood scale. Research at larger geographic scales (e.g., county, cities, and metropolitan areas) may be more appropriate for informing land use planning for larger areas.²² In addition, the focus on parks and other public greenspace excludes other green environments (e.g., private lands) that can support outdoor activities.²² Analyses at larger scales and inclusion of public and private lands follow current practice related to green infrastructure and land use planning. In particular, focusing on green infrastructure and natural ecosystems can provide information on dynamic natural ecological networks on which parks and open space depend.^{23,24} Lastly, how changes in greenspace composition and structure associated with increasing urbanization relate to physical activity and weight status have not been considered. This study examines associations between the fragmented characteristics of urban vegetative cover and physical activity and weight status controlling for socioeconomic factors in counties in U.S. metropolitan statistical areas (MSAs) greater than 1 million in population.

Vegetative cover fragmentation describes the change in forest composition and configuration through the process of urbanization.^{25–27} Fragmentation can be characterized as number and density of fragments or patches; connectivity of patches; and their accessibility, cohesion, and distance between them.^{28–33} Although fragmentation of urban ecosystems has been shown to have negative impacts on natural ecological systems (e.g., disruption of wildlife habitat), its potential effects on physical activity and weight status have not been explored. Prior research suggests greater extent of vegetative cover is likely related to physical activity and weight status, as it constitutes green infrastructure essential for activity spaces such as parks and trails. Findings from studies on urban sprawl lead to an expectation that increasing fragmentation will be negatively related to physical activity and positively related to weight status.³⁴ Finally, the authors expect that different configurations of fragmentation will have different relationships to physical activity and weight status. To summarize, this study addresses the following hypotheses:

1. Higher total vegetative cover will be positively related to physical activity and negatively related to weight status ($\text{BMI} < 25 \text{ kg/m}^2$).
2. More-fragmented vegetative cover will be negatively related to physical activity and positively related to weight status.
3. Different measures of fragmentation will have different relationships with physical activity and weight status.

Methods

Data were obtained for U.S. metropolitan statistical area with population > 1 million ($N=52$) to focus on the largest MSAs in the country.^{22,35} Relationships were analyzed at the county level.

Although 421 counties comprised the 52 MSAs, both health data and land cover data were only available for 135 counties (Figure 1).

Measures

The Selected Metropolitan/Micropolitan Area Risk Trends from 2008 derived from the Behavioral Risk Factor Surveillance System provided data for physical activity and BMI. The data set provides annual local area estimates for counties and MSAs. However, 286 of 421 counties did not have the estimates for this study owing to small sample sizes. Physical activity was based on self-reported measures of respondent participation in any physical activity other than regular work in the past month, including any duration and intensity. BMI was a calculated variable derived from self-reported body weight and height. For the analysis, physical activity was measured as the percentage of residents within the county indicating participation in physical activity other than work. BMI was measured as the percentage with BMI $<25 \text{ kg/m}^2$, indicating normal BMI.

The definition of “vegetative cover” includes greenspaces and areas with green elements. The National Land Cover Database (NLCD) 2006 provided data on vegetative cover. The NLCD provides complete land cover data for the coterminous U.S. from Landsat Thematic Mapper at 30-meter resolution.³⁶ The NLCD Level I classification includes eight types: forest, shrubland, herbaceous, planted/cultivated, barren, developed area, water, and wetlands. The NLCD has been a data source for previous research on health and greenspace.³⁷ Of primary interest in this study were vegetative covers, including forest, shrubland, and herbaceous types. Forest refers to areas with woody vegetation (including deciduous, evergreen, and mixed forests) >6 meters in height; shrubland is defined as areas with woody vegetation (including shrubs in early successional stage

or trees stunted by weather conditions) and young trees <6 meters; and herbaceous refers to areas with grassland or herbaceous vegetation (e.g., grasses, wildflowers). Accuracy for the NLCD Level I is 84%.³⁸

Several metrics are commonly used to measure degree of land cover fragmentation representing landscape composition and configuration, relative differences among land cover patches, and the degrees of aggregation or clumping of patch types.^{39,40} Seven land cover metrics, including percentage of green land cover, patch area, patch density, edge density, edge contrast index, Euclidean distance, and patch cohesion index, were selected based on the major characteristics of urban forest fragmentation and potential influence on ecosystem and human health.^{8,28–33,41–44}

These seven landscape metrics are categorized into three domains:

1. area-edge, landscape composition, and the simplest configuration;
2. contrast, the relative distance among patch types; and
3. aggregation or the degree of clumping of patch types.⁴⁵

The specific metrics for each domain are described in Table 1. Area-edge metrics reflect the availability of vegetative covers. The authors expected that greater abundance would correlate with greater physical activity and normal BMI. Contrast measures reflect possibility of movement between patch types (e.g., residential areas and vegetative covers) that potentially provide more access for physical activity. Conversely, greater aggregation or clumping of patch types could increase difficulty of access for activity. Greater patch density can increase opportunity for people to contact with vegetative covers, as urban vegetation fragmentation breaks up large patches into many small patches. In the absence of prior theory and evidence,

differences are expected in how each metric associates with physical activity and BMI. Higher values of patch density, edge density, edge contrast, and Euclidean distance indicate more fragmentation; conversely, higher values for percentage of land cover, patch area, and cohesion indicate less fragmentation. All fragmentation metrics were generated in 2013 using FRAGSTATS, version 4.2, a spatial pattern analysis program designed to compute a variety of landscape metrics.⁴⁵

Total population, total housing units, median household income, and percentage black/African American population for each county were obtained from the American FactFinder, U.S. Census Bureau and were treated as possible confounding variables.⁴⁶ Population and housing density served as proxy indicators for built environment^{47,48} and were calculated using the total population and housing units divided by the total land area of the county, respectively, using ArcGIS®, version 10.

Statistical Analysis

Analyses were conducted from August to December 2013 using SPSS, version 19 and R, version 2.14.1. Bivariate and multivariate relationships among vegetative cover and physical activity and BMI were examined by Spearman's rank correlation and regression models, respectively. Regression models included stepwise and hierarchical regressions. Stepwise regression was used first to find the best-fit model for predicting physical activity and BMI using the Akaike Information Criterion⁴⁹ as the selection criterion. Subsequently, hierarchical regression was used to test the best-fit models with potential confounders and the variance inflation factor was used to adjust the models for potential multicollinearity. Hierarchical models are appropriate for

estimating associations between land cover variables and the outcomes while controlling for potential confounders.⁵⁰

Results

The percentage of county residents participating in non-work physical activity ranged from 65.1% to 90.2% with a mean of 77.06% (SD=4.92). The percentage of normal BMI ranged from 24.1% to 55.5% with a mean of 38.02% (SD=5.42). Forest, shrubland, and herbaceous vegetation at the national scale accounted for 42.79% of all land cover. Developed area was the highest percentage among all land cover types at 30.47%. Seven fragmentation metrics were generated for vegetative covers. Mean patch area for vegetative covers ranged from 3.5 m² (herbaceous) to 17.46 m² (forest). Mean patch density ranged from 0.77 patches per 100 ha (herbaceous) to 1.53 patches per 100 ha (forest). Mean edge density ranged from 10.53 m/ha (herbaceous) to 41.62 m/ha (forest). Mean edge contrast index ranged from 20.32% (shrubland) to 44.41% (forest). Mean Euclidean distance ranged from 211.62 m (forest) to 673.50 m (herbaceous). Mean patch cohesion index ranged from 83.96% (herbaceous) to 95.91% (forest). Mean population density was 1,087.70 per km² (SD=2,751.05), mean housing density was 482.55 km² (SD=1,373.29), mean median household income was U.S. \$63,035.12 (SD=15,900.59), and mean percentage of black/African American population was 15.89% (SD=14.15).

Bivariate and multivariate relationships (Tables 2 and 3) among vegetative cover and physical activity and obesity were examined. Only physical activity correlated significantly with vegetative cover. All three vegetative covers (forest, shrubland, and herbaceous) were

significantly and positively correlated with physical activity. Patch density of herbaceous vegetation exhibited the strongest correlation with physical activity ($\rho=0.35$, $p<0.001$). In multivariate relationships, when adjusting for all other variables, edge density of forest type ($\beta=0.272$, $p<0.05$) and larger size of herbaceous patches ($\beta=0.261$, $p<0.01$) were significant predictors of physical activity. The model explained 35.3% of the variance in physical activity prevalence in the study counties.

There were no significant bivariate correlations between vegetative cover and normal BMI. Yet, the multivariate BMI model explained 33.5% of the variance in BMI adjusting for potential confounders. More connections between forest type and developed area ($\beta=0.37$, $p<0.01$), greater edge density of shrubland type ($\beta=0.646$, $p<0.001$), and larger size of herbaceous patches ($\beta=0.332$, $p<0.01$) were associated with a greater proportion of normal BMI. Higher patch density of shrubland type ($\beta= -0.504$, $p<0.01$) was associated with lower proportion of normal BMI.

Discussion

Urban vegetative cover provides critical ecosystem services important for public health. Consistent with expectations, this study's results showed that more physical activity tended to be associated with greater amounts of vegetative cover at the county scale based on bivariate analyses. These findings align with previous studies that found positive associations between urban greenspace and physical activity.^{12,51} In addition, multivariate analyses showed results consistent with reports that demonstrate the importance of accessibility^{8,42,52} and size^{53,54} for use of parks, park-based physical activity, and walking.⁵³ The results differ from European studies in

which significant associations were not observed between greenspaces and levels of physical activity.^{51,55,56} Overall, findings are in agreement with studies showing that greenspace is positively related to overall health.⁵⁷

Findings involving land cover fragmentation ran counter to the study hypotheses, specifically the expected negative correlation with physical activity. Urban vegetative cover is typically fragmented by residential and commercial development, leading to the reduction of patch size and increases of patch density and edge density.^{29,30,33} Research on urban forest fragmentation has found negative impacts on ecosystem structure and function such as disruption of wildlife habitat and introduction of invasive species.⁵⁸ The present analyses suggest that edge fragmentation within counties may be beneficial for physical activity possibly because more access and opportunities are created for people to enjoy natural greenspaces for recreation. Landscape preference studies have shown that recreationists prefer forest recreation settings with edge-like characteristics.^{44,59–61} Consistent with past research, bivariate results showed forest patch density was positively associated with physical activity, suggesting that more greenspace parcels provide more opportunities for people to engage in physical activity.⁸ However, the results from the multivariate analysis showed that patch density of shrubland was negatively associated with normal BMI. This may indicate that this vegetative type among other land cover types is less conducive for promoting healthy weight at the population level.

In view of the large body of literature linking greenspace and health, this study contributes by showing that type of vegetative cover in addition to its ecological character are important in understanding how greenspace is related to health outcomes. For example, forest patches with

greater edge were associated with greater prevalence of activity and greater shrubland edge density associated with positively physical activity and normal BMI. Such findings can inform ongoing attempts to assess what types, configuration, and amount of greenspaces are needed to achieve public health goals.

Findings from this study can encourage theorizing on mechanisms by which vegetative cover and fragmentation relate to physical activity. Mass and colleagues⁵¹ suggest that certain configurations of different land cover types and fragmentation patterns may create suitable infrastructure for outdoor recreation settings that can support activity. In addition, fragmentation pattern effects on ecosystem services could exert influence through other ecological factors including bird species richness, which could be linked to psychological benefits of greenspace.⁶²

Limitations

Several limitations should be acknowledged. First, the cross-sectional study design did not allow for analysis of temporal effects or causality with respect to land cover change and health outcomes. Moreover, owing to self-selection (that people choose where they live and are not randomly assigned), it may be that populations inclined to be physically active tend to live in areas with certain land cover patterns. Land use patterns could also reflect the preferences of populations supportive of environmental policies that promote active living. Future studies should take advantage of time series data to examine how changes in land cover influence population physical activity and weight status. Second, the health data used in the analysis were based on self-report measures using dichotomous coding and aggregated to the county level, which often lead to certain biases (e.g., construct validity).⁶³ As a result, objective measures of physical activity (e.g., measured by accelerometer) and BMI (calculated from measured height

and weight) were not used. However, previous studies have reported acceptable reliability and validity of BRFSS physical activity measures.^{64,65} The present study did not analyze intensity or extent of habitual activity. In view of past uses of the BRFSS, a single-item measure is adequate for classifying respondents into active and inactive groups for this study.⁶⁴ Furthermore, not all the counties within a MSA have a measure because of small sample size. A third limitation relates to the quality of land cover data. Analyses relied on land cover data captured at 30-meter resolution. Data from higher spatial resolution (e.g., 10-meter or less) may be more effective in providing greater detail in land cover. Related to this, it would also be important to capture health data at similar scales (e.g., block or postal ZIP code level). Fourth, the analyses did not control for additional built environment variables (e.g., sidewalks, trails, etc.) known to associate with physical activity, as well as potential land uses for future recreational uses (e.g., grayfields and brownfields).⁶⁶ Finally, in view of potential ecological fallacy biases, the authors caution readers to recognize that the findings address county-level prevalence and associations and not individual behaviors.

Conclusions

Strengths of this study included the detailed characterization of urban vegetative cover and its associations with physical activity and BMI for the U.S. largest metropolitan areas. Second, the study examined vegetative cover within the broader context of green infrastructure and ecological networks more suitable for regional land use planning.^{67,68} Building on previous research,³⁷ this study provides an example of how to integrate land cover and health surveillance data (e.g., BFRSS) to explore associations between vegetative cover and public health. Further studies are needed to identify and evaluate how specific land cover metrics influence health, explore optimal configurations of land cover types for desired health outcomes, and increase

understanding how policy processes can be used to achieve optimal configurations for health in urban areas.

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Figure 1. Study area.

Note: Metropolitan statistical areas with population over one million were selected (N=52).

These 52 MSAs comprised 421 counties, however, only 135 counties were included in this study due to data limitation.

Table 1. Selected Fragmentation Metrics in This Study

Domain	Metrics	Unit	Description
Area-Edge: <i>Measure landscape composition and the simplest configuration</i>	Percentage of land cover (%)	%	The proportional abundance of each patch type in the landscape
	Patch area (AREA)	m ²	Mean of the total area of the corresponding patch type
Contrast: <i>Measure the relative difference among patch types</i>	Edge density (ED)	m/ha	The sum of the lengths of all edge segments involving the corresponding patch type in an area
	Edge contrast index (ECON)	%	The sum of the patch perimeter segment lengths multiplied by their corresponding contrast weights (i.e., developed area and forest, shrubland, or herbaceous types were weighted by 1, and all others were weighted by 0 in this study) divided by total patch perimeter
Aggregation: <i>Measure the degree of aggregation or clumping of patch types</i>	Patch density (PD)	#/100ha	The number of patches of the corresponding patch type per 100 hectares
	Euclidean distance (ENN)	m	ENN equals the distance (m) to the nearest neighboring patch of the same type, based on shortest edge-to-edge distance.
	Patch cohesion index (COHESION)	%	The physical connectedness of the corresponding patch type measured by its perimeter, total area, and number of patches

Table 2. Significant Bivariate Relationships of Vegetative Cover Characteristics With Physical Activity

Physical activity					
Metric	<i>rho</i>	Metric	<i>rho</i>	Metric	<i>rho</i>
% Forest	0.257**	% Shrubland	0.215*	%Herbaceous	0.327***
Forest_AREA	0.202**	Shrubland_PD	0.263**	Herbaceous_PD	0.350***
Forest_ED	0.253**	Shrubland_ED	0.239**	Herbaceous_ED	0.339***
Forest_ENN	-0.216*	Shrubland_ECON	-0.206*	Herbaceous_ECON	-0.213*
Forest_COHESION	0.232**			Herbaceous_ENN	-0.250**

Note: Boldface indicates statistical significance (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

There is no significant bivariate relationships between vegetative characteristics and normal BMI.

% is percentage of land cover (%); AREA is averaged patch area (m²); PD is patch density (#/100ha); ED is edge density (m/ha); ECON is edge contrast index (%); ENN is Euclidean distance (m); and COHESION is patch cohesion index (%).

Table 3. Multivariate Relationships of Vegetative Cover Characteristics With Physical Activity and Normal BMI

	Physical activity					Normal BMI				
	Unstandardized coefficients	Standardized coefficients	VIF	95% CI for B		Unstandardized coefficients	Standardized coefficients	VIF	95% CI for B	
Variables	B	Beta		Lower Bound	Upper Bound	B	Beta		Lower Bound	Upper Bound
% Forest	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	6.54E-02	0.225	3.76	-1.44E-02	1.45E-01
Forest_AREA	5.52E-03	0.022	1.52	-3.87E-02	4.98E-02	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>
Forest_ED	5.20E-02*	0.272*	2.59	8.86E-03	9.52E-02	-4.57E-02	-0.221	5.52	-1.15E-01	2.31E-02
Forest_ECON	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	8.03E-02**	0.370**	2.45	3.21E-02	1.28E-01
Shrubland_AREA	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	-3.64E-03	-0.030	1.51	-2.48E-02	1.75E-02
Shrubland_PD	-1.33E+00	-0.291	4.68	-2.72E+00	5.94E-02	-2.49E+00**	-0.504**	4.97	-4.05E+00	-9.29E-01
Shrubland_ED	7.91E-02	0.287	4.91	-6.51E-03	1.65E-01	1.92E-01***	0.646***	5.35	9.47E-02	2.90E-01
Shrubland_ENN	-1.94E-04	-0.053	1.34	-7.93E-04	4.04E-04	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>	<i>NS</i>
Herbaceous_AREA	2.31E-01**	0.261**	1.85	6.20E-02	3.99E-01	3.18E-01**	0.332**	1.94	1.29E-01	5.07E-01
Herbaceous_ENN	-1.13E-03	-0.150	1.41	-2.38E-03	1.26E-04	-1.05E-03	-0.129	1.32	-2.38E-03	2.79E-04
Herbaceous_COHESION	-3.88E-02	-0.066	3.09	-1.84E-01	1.07E-01	-1.80E-01*	-0.281*	3.08	-3.38E-01	-2.05E-02
Population density	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>	<i>DL</i>
Housing density	2.69E-04	0.037	1.38	-9.22E-04	1.46E-03	1.31E-03	0.167	1.64	-1.14E-04	2.73E-03
Median household income	1.28E-04***	0.415***	1.67	7.20E-05	1.83E-04	8.72E-05**	0.262**	1.56	2.84E-05	1.46E-04
Race	-3.15E-02	-0.087	1.72	-9.83E-02	3.53E-02	-9.29E-02*	-0.237*	1.78	-1.67E-01	-1.88E-02
Adjusted R ²	0.353					0.335				

Note: Boldface indicates statistical significance (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

VIF, Variance Inflation Factor; DL, Deleted from final selected model due to high VIF (>10); NS, Not selected into model.

% is percentage of land cover (%); AREA is averaged patch area (m²); PD is patch density (#/100ha); ED is edge density (m/ha); ECON is edge contrast index (%); ENN is Euclidean distance (m); and COHESION is patch cohesion index (%)