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Journal

Annals of Epidemiology, 28(4)

Authors

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Publication Date

2018-04-01

DOI

10.1016/j.annepidem.2018.01.009

Peer reviewed

HHS Public Access

Author manuscript

Ann Epidemiol. Author manuscript; available in PMC 2019 April 01.

Published in final edited form as:

Ann Epidemiol. 2018 April ; 28(4): 213–219. doi:10.1016/j.annepidem.2018.01.009.

The relationship between surrounding greenness in childhood and adolescence and depressive symptoms in adolescence and early adulthood

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Abstract

Purpose—Exposure to nature, particularly vegetation (greenness), may be beneficial for mental health. We investigated whether higher surrounding greenness in early life was associated with subsequent reduced risk of depressive symptoms, and whether this association was modified by age, sex, or population density.

Methods—Participants from the Growing Up Today Study were included if they reported on depressive symptoms between 1999 and 2013. Greenness exposure was characterized as the cumulative average normalized difference vegetation index value (1000 meter resolution) from 1989 until two years before outcome assessment or age 18 based on geocoded addresses. We defined high depressive symptoms as the top 10% of scores on the McKnight Risk Factor Survey or the Center for Epidemiologic Studies of Depression scale, depending on the questionnaire. Data

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were analyzed using Cox proportional hazards models adjusted for socioeconomic status and other confounders.

Results—There was a 6% lower incidence of high depressive symptoms associated with an interquartile range increase in greenness (95% CI 11%-0%). This relationship was stronger in higher population density areas (>1000 people/mi^2, 8% lower incidence, 95% CI 15%-1%).

Conclusions—Living in an area with greater surrounding greenness during childhood may be beneficial for mental health, particularly in more urban areas.

Keywords

Mental Health; Depression; Environment Design; Residence Characteristics

Introduction

The relationship between exposure to natural environments and mental health is an emerging area of research. There has been a particular focus on vegetation, with many studies investigating surrounding residential greenness as a marker of exposure to nature.[1,2] Studies in the United States and around the world have shown that living in an area of higher surrounding greenness or living in closer proximity to a green space is associated with better mental health.[1–5] Nature can improve physiological and psychological stress responses,[6] restore attention,[7] facilitate social interaction,[8,9] and encourage physical activity,[10,11] all of which may result in improved mental health outcomes.[1,12,13] While this research has focused on multiple measures of mental health such as emotional resilience,[14,15] anxiety,[16] and general psychiatric morbidity,[17] depression or depressive symptoms has received particular attention.[18,19] Given that depression is expected to be the leading cause of morbidity in high-income countries by 2030[20] and represents a substantial and increasing economic burden,[21] identifying modifiable factors that may protect against depression is a public health priority.

There is also growing recognition of the importance of a life course approach to understanding the determinants of health.[22] Early life and childhood represent critical periods for many exposures, with the effects of many childhood exposures persisting into adulthood.[23–25] Much of this research has focused on the lasting mental health impacts of potentially harmful psychosocial childhood exposures (e.g. violence[26] and bullying[27]). Higher neighborhood socioeconomic status (SES) during childhood has been linked to improved adult mental health, independent of adult exposures,[23,24] but limited evidence exists for other contextual factors.[28] Only one study of which we are aware has specifically investigated whether childhood exposure to greenness or other forms of nature is associated with reduced risk of poor mental health, specifically depression, in adulthood.[29]

In this study, we consider the prospective relationship between surrounding greenness during childhood and adolescence and depressive symptoms in adolescence and adulthood, and whether these relationships are modified by age of first depression onset (before or after age 18) or population density.[30,31,32] We hypothesize that greater surrounding greenness during

childhood and adolescence is associated with lower onset and persistence of high depressive symptoms.

Methods

Study population

We used data from the prospective cohort Growing Up Today Study (GUTS). GUTS was founded in 1996 by inviting women in the ongoing Nurses' Health Study II (NHSII)[33] to enroll any of their children who were between the ages of 9–14. Completion and return of the initial questionnaire by the child implied informed consent and questionnaires have been sent directly to participants since 1996. Follow-up questionnaires have been sent annually or biennially. The study was approved by the Brigham and Women's Hospital Institutional Review Board.

A total of 13,754 participants completed at least one questionnaire measure of depressive symptoms between 1999 (when this was first asked) and 2013. The exposure, surrounding greenness during childhood, was assigned based on the mother's home address (available biennially since 1989). We assumed GUTS participants lived with their mothers until age 18 unless they had provided information to suggest otherwise. We excluded participants who reported living with someone other than their mother (N=2,067) or attending military or boarding school (N=72) prior to the age of 18. We further excluded 269 participants who did not have a valid address or lived outside the contiguous United States for all of childhood. Our final sample size for the primary analysis was 11,346 participants. In secondary analyses of persistent depression, we limited the study population to participants who completed questions on depressive symptoms on at least 3 questionnaires (N=8,374).

Outcome

Our main outcome of interest was high depressive symptoms, assessed via self-report using two different symptom scales based on participant ages. In 1999, 2001, and 2003, depressive symptoms were assessed using the McKnight Risk Factor Survey (MRFS)[34] while in 2007 and 2010, the Center for Epidemiologic Studies ten-item depression scale (CES-D 10) was used.[35] The MRFS, validated for adolescents and pre-adolescents, includes six items asking the extent to which individuals experience the following symptoms on a five-point Likert scale ranging from never to always: worthlessness, low energy, depressed, hopeful, trouble concentrating, trouble enjoying usual activities. [34] The CES-D 10, validated for use in adolescents and young adults, includes ten items asking the extent to which individuals experience the following symptoms on a four-item Likert scale ranging from rarely or none of the time to all of the time: bothered, trouble concentrating, depressed, effort, fearful, restless sleep, lonely, trouble getting going, hopeful, happy.[36,37] Scores on the MRFS and the CES-D were highly correlated in a cross-sectional validation study conducted in adolescent and preadolescent girls[34]

For both the MRFS and the CES-D, a mean score was calculated for each participant at each time point from available responses. Consistent with previous approaches,[38] for the MRFS, which contains six items, individuals missing one of the six items were eligible (N=136 in

1999; N=81 in 2001; N=166 in 2003) while those missing two or more were excluded (N=6 in 1999; N=10 in 2001; N=23 in 2003). For the CES-D, which contains 10 items, individuals missing between one and three items were eligible (N=318 in 2007; N=163 in 2010; N=107 in 2013) while those missing four or more were excluded (N=9 in 2007; N=10 in 2010; N=11 in 2013).

Estimates of the 12-month prevalence of depression in adolescents and young adults in the United States range from 8.7% to 11.3%.[39] We dichotomized our sample to define cases of high depressive symptoms as the top 10% of the distribution for each questionnaire.[38] We created a second case definition of "persistent high depressive symptoms," for individuals who had high depressive symptoms at least three times, consistent with previous publications from this cohort.[38]

Exposure

Our exposure of interest was surrounding greenness during childhood and adolescence. Greenness was characterized using the Normalized Difference Vegetation Index (NDVI), a measure of vegetative density.[1] NDVI leverages the fact that chlorophyll in plants absorbs visible light (0.4–0.7 μm), while reflecting near-infrared light (0.7–1.1 μm), to calculate a continuous measure of vegetation density from the ratio of the difference between these spectra to their sum.[40] NDVI was downloaded from the Advanced Very High Resolution Radiometer (AVHRR), a remote sensing instrument operated by the National Oceanic and Atmospheric Administration. These data are available at a one kilometer resolution and scaled to a range of −1 to 1. Values less than 0 indicate water and higher values indicate greater density of vegetation. To capture the peak greenness level and maximum variability in greenness, we used mid-July NDVI values to characterize surrounding greenness for each year.

We assigned individual greenness exposure to each participant's residential history. Time-varying greenness exposure was calculated as the cumulative average NDVI value from 1989 to age 18 (for depression measures in adulthood and persistent depression) or two years before outcome assessment (for depression measures in adolescence). We modelled continuous NDVI scaled by the interquartile range (IQR).[41–43]

Covariates

We included covariates measured at the individual, household, and neighborhood levels as potential confounders. We used data reported by mothers to characterize household SES according to income in 2001 (dichotomized at $75,000 per year). We also used data on paternal education (college graduate versus not). GUTS participants also reported their race/ethnicity (white/other race) on the baseline questionnaire; other individual-level covariates were age and sex. Participants were considered to have a maternal history of depression (ever/never) if their mothers ever reported antidepressant use or depression diagnosis, or if they scored below the cutoff (less than 53 on a scale of 0 to 100) for probable depression on the Mental Health Inventory.[44,45] Missing data on household income, parental education, and participant race were characterized with a missing indicator.

We used data from the 2000 U.S. Census to characterize cumulative average neighborhood population density, SES, and demographics matched to the timing of each NDVI measure. Census tract SES variables assessed for each address included median income, home value, percent white, and percent college educated.[46] Since air pollution may be a confounder or an intermediate in the association between greenness and depression, we additionally considered models adjusted for residential address-level estimates of annual average particulate matter less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$). $PM_{2.5}$ was estimated from validated GIS-based spatio-temporal models[47].

Statistical Analysis

For our primary analysis we used Cox proportional hazards models using calendar time in months as the time scale. Participants were followed from the time of the return of the 1996 questionnaire to first report of high depressive symptoms, return of the 2013 questionnaire, or the date of the last returned questionnaire if lost to follow-up. All models were stratified by age (in months) and questionnaire cycle. In multivariable models we added participant race and gender, household income, paternal education, maternal history of depression, and the census tract measures. In a third set of models we further adjusted for estimated $PM_{2.5}$. We used a robust sandwich covariance matrix to account for non-independence of sibling clusters.[48]

We also considered whether childhood greenness was associated with persistent high depressive symptoms using logistic generalized estimating equations with robust variance estimators to account for sibling clusters. We regressed the binary outcome of persistent depressive symptoms on cumulative average greenness from 1989 to age 18. In adjusted models we included race, household income, paternal education, maternal history of depression, and cumulative average measures (also calculated from 1989 to age 18) for the census tract variables. To assess whether observed associations were independent of air pollution we further adjusted for estimated $PM_{2.5}$.

We examined the possibility of a non-linear relation between greenness exposure and the odds of depressive symptoms non-parametrically with restricted cubic splines.[49] Some previous studies have observed the relationship between greenness and health to vary by population density or urbanicity.[31,32] We therefore considered whether the results were modified by Census tract population density, dichotomized as low (≤1000 people/mi^2) or high (>1000 people/mi^2).[50] Since our exposure was only updated through age 18, we evaluated whether the relationship between surrounding greenness and depression differed between cases that occurred up to age 18 and those that occurred after. We also assessed effect modification by sex, since patterns of depressive symptoms differ between males and females.[51] We tested interaction terms for statistical significance using a Likelihood Ratio Test for Cox proportional hazards models and a generalized score test for logistic regression models; we also evaluated stratified models.

Results

The 11,346 participants included in this study were predominantly white (93%) and female (58%) (Table 1). Participants who grew up in areas with higher NDVI were more likely to

come from households making less than $75,000 per year, be white, and live in Census tracts with lower levels of college education and greater proportions of whites.

In age-adjusted models higher greenness was significantly associated with 7% reduced hazard of developing depressive symptoms for 1-IQR (0.148) higher greenness (Table 2), and there was no evidence of deviations from linearity. HRs were slightly attenuated after adjusting for all covariates, with a 5% lower incidence of high depressive symptoms per IQR increase in greenness (95% CI 11% lower to 1% higher). Further adjustment for $PM_{2.5}$ did not substantially alter any of the observed associations.

Stratified models suggested a potentially stronger association among individuals who lived in a higher population density census tract (p for interaction 0.15). In high density areas, an IQR increase in greenness was associated with 8% lower incidence of high depressive symptoms (95% CI 15% to 1% lower) while the association in low density areas was not statistically significant (Table 2). Although the interaction between greenness and age above or below 18 was not statistically significant (p=0.43), stratified models suggested a slightly stronger association in participants with younger-onset depression.

For persistent depression, there was evidence of deviations from linearity so results of a restricted cubic spline are presented in Figure 1 while linear models are presented in Table 3. There was moderate evidence that growing up in an area with higher NDVI was associated with lower odds of persistent depression in the population overall, but this association was attenuated at the highest levels of greenness (Figure 1). There was statistically significant evidence (p=0.02) for an interaction between greenness and high versus low population density. Results of stratified models are presented in Figure 2 and Table 3. There was no evidence of effect modification by sex for either outcome.

Discussion

In this study of US adolescents and young adults followed for up to 17 years, we observed an association between higher NDVI during childhood and adolescence and lower risk of subsequent depressive symptoms. These associations appeared stronger in adolescence than in early adulthood, and in areas of high population density. We observed a similar pattern when considering persistent depressive symptoms.

Our findings are similar to those of a retrospective study of Australian adults which observed that greater contact with nature in childhood was moderately correlated with lower depressive symptoms in adulthood.[29] This association was primarily mediated through adult contact with nature. This study was able to characterize contact with nature rather than simply presence of nature, but relied on self-reports and was unable to control for SES in childhood.

This study complements a small but growing number of prospective studies evaluating a potentially protective association between greenness or green space and risk of depression.[19,52,53] Gubbels et al. measured depressive symptoms at two time points 1–2 years apart and observed changes associated with an increase in perceived greenery among adults but not adolescents.[19] Other prospective studies[5352] have observed similar beneficial relationships

between greater greenness and improved depressive symptoms or lower risk of depression in adults.

We observed a suggestion of a stronger association between NDVI and depressive symptoms in areas of high population density. Many previous studies of greenness and mental health, particularly those with repeated follow-up measures, focus on a single metropolitan area or other relatively homogenous region.[54–56] Indeed much of the literature on greenness or green space and mental health has focused specifically on urban areas.[2–4,12] Few population-based studies have considered how this relationship varies across population density, but studies of other health outcomes have observed similarly stronger associations in denser or more urban areas.[31,32] Our results suggest that the relationship between greenness and health may be most salient for people living in areas of higher density, a finding consistent with underlying mechanisms. Urban areas can consistently tax attention and cognition[30] and impose greater stress and social demands on residents than areas of lower population density.[57] Greenness and other forms of nature can act as an antidote to these influences by providing a restorative break for cognition and attention[13,30] and reducing stress.[6]

We observed a suggestion of stronger associations between surrounding greenness and onset of high depressive symptoms before age 18. Since exposure was only characterized through age 18, it is possible that more proximal exposures are important. The analysis of depressive symptom onset after age 18 was limited to individuals who were free of depression up to that point and excluded the 1,260 individuals who were characterized as having high depressive symptoms as teenagers. Since depression in adolescence is a strong predictor of depression in adulthood[58,59] it is also possible a sample limited to newly onset depression in adulthood represents a distinct subset for whom childhood exposures are less relevant.

Some important limitations must be noted. We relied on NDVI measured at a one kilometer resolution. There is no consensus in the literature about the most relevant spatial area for characterizing greenness in relation to mental health, and the use of this relatively large area may have failed to capture the relevant geographic context. Other studies of adolescent health have considered multiple spatial resolutions and observed the strongest associations at 1,000 meters.[60] Measurement error in our exposure may also result from using only residential address, and not locations of other places where children may spend time. NDVI also does not provide information on how participants interact with greenness or its type or quality. There may also be some misclassification of depression status since depressive symptoms were measured rather than clinical diagnosis. Additionally, since depression was not assessed on the first GUTS questionnaire we assumed all participants were free of depression at baseline. While this likely resulted in some misclassification of new cases of high depressive symptoms, because our exposure was a cumulative average measure across childhood and therefore highly correlated over time, we do not expect this assumption to substantially bias our estimates.

Our study participants were predominantly white and resided in census tracts that were, on average, more affluent than a typical U.S. neighborhood. All participants had mothers who were nurses, suggesting some level of economic and social stability in their lives. As a result, caution should be exercised in generalizing the findings. However, some previous

studies have shown stronger associations in less advantaged individuals and communities so it is possible our observed associations would underestimate the associations in less advantaged settings.[14,61]

This study also had some unique strengths, including detailed prospectively assessed residential history available for nearly all of childhood for participants growing up across the United States. We were able to characterize cumulative childhood NDVI, an improvement over studies that relied on exposure characterized at a single point in time. We also had repeated measures of depressive symptoms, which enabled us to characterize the association between greenness and depressive symptoms across the transition from adolescence to adulthood.

Conclusion

In this analysis of more than 11,000 young adolescents followed into early adulthood living in the United States, we observed higher surrounding greenness in childhood and adolescence was associated with lower incidence of high depressive symptoms. This association was limited to areas of higher population density and suggestively stronger in adolescent-onset than in adult-onset depressive symptoms. We observed a suggestive but not significant association between surrounding greenness in childhood and adolescence and persistent depression in the population overall, but we did observe an association among individuals who grew up in higher density areas. Our findings suggest that greater surrounding greenness during childhood and adolescence may be beneficial for mental health, particularly for individuals living in areas of higher population density.

Acknowledgments

Funding Source

This work was funded by the National Institutes of Health (grants T32 ES 007069, K99 CA201542, R01 HD066963, R01 HD057368, P30 ES000002, R01 ES017017, and R01 DK084001)

Abbreviations

NDVI	Normalized Difference Vegetation Index
IQR	Interquartile range
AVHRR	Advanced Very High Resolution Radiometer
CI	Confidence Interval
SES	Socioeconomic Status
GUTS	Growing Up Today Study
NHS II	Nurses' Health Study II
MRFS	McKnight Risk Factor Survey
CESD-10	Center for Epidemiologic Studies ten-item depression scale

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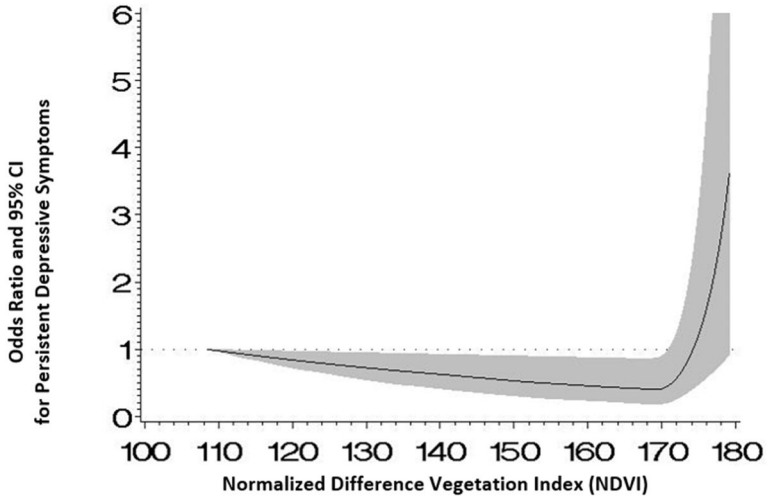

Figure 1. Restricted cubic spline for the adjusted association[a] between surrounding greenness in childhood and persistent depression[b] in 8,375 adolescents and young adults (N=295 cases) living in the United States

[a] Results quantified from logistic regression models with a generalized estimating equation are expressed as odds ratio for high depressive symptoms. Adjusted for participant race and gender, household income, maternal history of depression, paternal education, and census tract median household income, median home value, percent white, and percent college educated

[b] Defined as high depressive symptoms on three or more questionnaires over the study period (1999–2013)

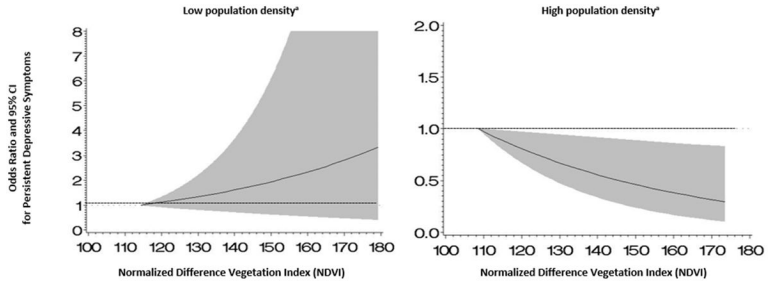

Figure 2. Restricted cubic splines for the adjusted association[b] between surrounding greenness in childhood and persistent depression[c] in 8,375 adolescents and young adults (N=295 cases) living in the United States, stratified by population density

[a] Low population density: ≤1000 people/mi^2; High population density >1000 people/mi^2

[b] Results quantified from logistic regression models with a generalized estimating equation are expressed as odds ratio for high depressive symptoms. Adjusted for participant race and sex, household income, maternal history of depression, paternal education, and census tract median household income, median home value, percent white, and percent college educated

[c] Defined as high depressive symptoms on three or more questionnaires over the study period (1999–2013)

Table 1

Cumulative average characteristics of 11,346 adolescents and young adults in the Growing Up Today Study (GUTS) who reported depressive symptoms between 1999 and 2013

	All participants	NDVI Tertile 1 (least green)[a] N=3,783	NDVI Tertile 2 N=3,782	NDVI Tertile 3 (most green) N=3,781
Individual Measures	%	%	%	%
Female *(%)*	58	58	59	57
White (%)[b]	93	88	96	97
Household Income Reported in 2001[c]				
≥$75,000 (%)	63	68	63	59
Father's Education[d]				
College or Greater (%)	65	70	66	59
Maternal History of Depression (%)	29	29	30	28
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Normalized Difference Vegetation Index (NDVI)[e]	0.57 (0.12)	0.44 (0.09)	0.59 (0.03)	0.69 (0.03)
Average $PM_{2.5}$ ($\mu g/m^3$)[e]	13.8 (2.7)	13.9 (3.4)	14.5 (2.1)	12.9 (2.2)
Baseline Age (1996)	11.4 (1.6)	11.4 (1.6)	11.4 (1.6)	11.3 (1.6)
Census Tract Measures[e]	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
College Educated (%)	32 (16)	34 (16)	33 (16)	28 (16)
White (%)	89 (12)	81 (16)	91 (10)	95 (5)
Median Home Value ($)	163K (109K)	204K (136K)	149K (86K)	137K (85K)
Median Household Income ($)	65K (22K)	68K (22K)	65K (21K)	62K (21K)
Population Density (people/mi^2)	2867 (5337)	5440 (8292)	2298 (2152)	863 (1051)
	%	%	%	%
Low Density (≤1000 people/mi^2)	35	10	27	68
High Density (>1000 people/mi^2)	65	90	73	32

[a] NDVI tertiles based on cumulative average greenness from 1989 to age 18

[b] 35 participants missing data

[c] 2,122 participants missing data

[d] 854 participants missing data

[e] Reported values are cumulative averages from 1989 to age 18

Table 2

The relationship between surrounding greenness and high depressive symptoms in 11,346 participants in the Growing Up Today Study, 1996–2013.

	Person-Months	Cases	Age-Adjusted HR (95% CI)[a]	Fully-Adjusted[b] HR (95% CI)	Fully-Adjusted + $PM_{2.5}$[c] HR (95% CI)
Overall	1,296,215	2,545	0.93 (0.88, 0.97)	0.95 (0.89, 1.01)	0.94 (0.89, 1.00)
Population Density					
High (>1000 people/mi^2)	839,311	1,694	0.91 (0.86, 0.97)	0.92 (0.85, 0.99)	0.92 (0.85, 0.99)
Low (≤1000 people/mi^2)	456,904	851	1.00 (0.89, 1.12)	1.05 (0.91, 1.22)	1.05 (0.91, 1.22)
Age					
Cases before age 18	573,889	1,260	0.91 (0.85, 0.97)	0.89 (0.82, 0.98)	0.89 (0.81, 0.97)
Cases after age 18	722,326	1,285	0.94 (0.88, 1.01)	1.00 (0.91, 1.09)	0.99 (0.91, 1.08)

[a] Results quantified from Cox Proportional Hazards models are expressed as hazard ratio for high depressive symptoms associated with an interquartile range (IQR) change in greenness, where 1 IQR = 0.148

[b] Adjusted for participant race and sex, household income, maternal history of depression, paternal education, and census tract population density, median household income, median home value, percent white, and percent college educated

[c] Adjusted for participant race and sex, household income, maternal history of depression, paternal education, census tract population density, median household income, median home value, percent white, and percent college educated, and estimated $PM_{2.5}$

Table 3

Odds ratios and 95% confidence intervals for the relationship between surrounding greenness in childhood and persistent depression[a] in 8,374 adolescents and young adults (N=294 cases) living in the United States.

	N	Cases	Age-Adjusted OR (95% CI)[b]	Fully-Adjusted[c] OR (95% CI)	Fully-Adjusted + $PM_{2.5}$[d] OR (95% CI)
Overall	8,374	294	0.86 (0.74, 1.00)	0.87 (0.72, 1.06)	0.87 (0.72, 1.05)
Population Density					
High (>1000 people/mi^2)	5,440	197	0.76 (0.64, 0.91)	0.77 (0.61, 0.97)	0.77 (0.61, 0.97)
Low (≤1000 people/mi^2)	2,934	97	1.32 (0.88, 1.98)	1.32 (0.83, 2.11)	1.30 (0.83, 2.04)

[a] Defined as high depressive symptoms on three or more questionnaires over the study period (1999–2013)

[b] Results quantified from logistic regression models with a generalized estimating equation are expressed as odds ratio for high depressive symptoms associated with an interquartile range (IQR) change in greenness, where 1 IQR = 0.151

[c] Adjusted for participant race and sex, household income, maternal history of depression, paternal education, and census tract median household income, median home value, percent white, and percent college educated

[d] Adjusted for participant race and sex, household income, maternal history of depression, paternal education, census tract population density, median household income, median home value, percent white, and percent college educated, and estimated $PM_{2.5}$