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# Residential Green Space and Birth Outcomes in a Coastal Setting

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## Abstract

**BACKGROUND—**Residential green space may improve birth outcomes, with prior studies reporting higher birthweight among infants of women living in greener areas. However, results from studies evaluating associations between green space and preterm birth have been mixed. Further, the potential influence of residential proximity to water, or 'blue space', on health has not previously been evaluated.

**OBJECTIVES—**To evaluate associations between green and blue space and birth outcomes in a coastal area of the northeastern United States.

**METHODS—**Using residential surrounding greenness (measured by Normalized Difference Vegetation Index [NDVI]) and proximity to recreational facilities, coastline, and freshwater as measures of green and blue space, we examined associations with preterm birth (PTB), term birthweight, and term small for gestational age (SGA) among 61,640 births in Rhode Island. We evaluated incremental adjustment for socioeconomic and environmental metrics.

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Ethical approval:
The study protocol was approved by the Institutional Review Boards of Brown University, Women & Infants Hospital of Rhode Island, and the Rhode Island Department of Health.

Competing financial interests:
The authors have indicated they have no competing financial interests relevant to this article to disclose.

**RESULTS—**In models adjusted for individual- and neighborhood-level markers of socioeconomic status (SES), an interquartile range (IQR) increase in NDVI was associated with a 12% higher (95% CI: 4, 20%) odds of PTB and, conversely, living within 500 meters of a recreational facility was associated with a 7% lower (95% CI: 1, 13%) odds of PTB. These associations were eliminated after further adjustment for town of residence. NDVI was associated with higher birthweight (7.4 g, 95% CI: 0.4–14.4 g) and lower odds of SGA (OR=0.92, 95% CI: 0.87–0.98) when adjusted for individual-level markers of SES, but not when further adjusted for neighborhood SES or town. Living within 500 meters of a freshwater body was associated with a higher birthweight of 10.1 grams (95% CI: 2.0, 18.2) in fully adjusted models.

**CONCLUSIONS—**Findings from this study do not support the hypothesis that residential green space is associated with reduced risk of preterm birth or higher birthweight after adjustment for individual and contextual socioeconomic factors, but variation in results with incremental adjustment raises questions about the optimal degree of control for confounding by markers of SES. We found that living near a freshwater body was associated with higher birthweight. This result is novel and bears further investigation in other settings and populations.

### Keywords

green space; NDVI; blue space; pregnancy outcomes; epidemiology

## INTRODUCTION

More than 80% of the U.S and 50% of the global population now lives in urban areas (US Census Bureau, 2012; World Health Organization, 2013), where daily access to green environments with vegetation and open spaces is often limited. Residential neighborhood green space has been positively associated with overall self-perceived health (Maas et al. 2006) and with better mental (Alcock et al. 2014; Bowler et al. 2010; Gascon et al. 2015) and physical health and wellbeing (James et al. 2015; Lee and Maheswaran 2011; Villeneuve et al. 2012; Wilker et al. 2014). The putative health benefits of living in areas with more green space may be mediated by increased physical activity, reduced stress and improved psychosocial wellbeing, reduced noise and air pollution, and/or decreased ambient air temperature during periods of hot weather (Bowler et al. 2010; Dadvand et al. 2012a, 2014; Kihal-Talantikite et al. 2013; Laurent et al. 2013; Lee and Maheswaran 2011).

Some studies suggest that residential green space may also be associated with better health during pregnancy and lower risk of adverse birth outcomes. Specifically, higher levels of green space surrounding the maternal residence, frequently evaluated by the Normalized Difference Vegetation Index (NDVI, a satellite-based measure of the distribution of live green vegetation), have been consistently associated with indicators of improved fetal growth (Agay-Shay et al. 2014; Dadvand et al. 2012a, 2012b, 2014; Donovan et al. 2011; Dzhambov et al. 2014; Ebisu et al. 2016; Hystad et al. 2014; Laurent et al. 2013; Markevych et al. 2014), although associations with gestational length remain unclear (Agay-Shay et al. 2014; Casey et al. 2016; Cusack et al. 2017; Dadvand et al. 2012a, 2012b; Grazuleviciene et al. 2015; Hystad et al. 2014; Laurent et al. 2013). More limited work has assessed the influence of residential proximity to parks and other recreational natural environments on birth outcomes, with mixed findings for both mean birthweight and risk of preterm birth (Agay-Shay et al. 2014; Dadvand et al. 2012a; Grazuleviciene et al. 2015).

The varying influence of indicators of socioeconomic status (SES) on these associations may help to explain disparate results across studies. Socioeconomic characteristics at the individual and aggregate level are typically associated with features of the residential environment (Kihal-Talantikite et al. 2013) and highly predictive of birth outcomes (Andersen and Mortensen 2006; Racape et al. 2016; Weck et al. 2008). SES therefore likely has a considerable confounding influence on associations between residential green space, length of gestation, and fetal growth. However, it is important to balance the need to remove sources of confounding bias against the potential for overadjustment for highly correlated socioeconomic and environmental variables or variables on the pathway in question, for example if greener neighborhoods generate higher property values and drive measures of neighborhood SES (NSES) such as median household income higher (Chee et al. 2015; Cole et al. 2017). The optimal degree of adjustment to fully control confounding by individual- and neighborhood-level socioeconomic factors without attenuating estimation of the causal effect of interest has not been systematically parsed in the literature.

Further, associations between green space and birth outcomes may differ across subgroups defined by demographic characteristics such as education, race, and neighborhood-level SES. For example, socioeconomically advantaged individuals often have greater mobility and capacity to access green spaces away from their homes, while those of lower SES may be more dependent on the built environment proximal to their residence (Maas 2008; Maas et al. 2009; Schwanen et al. 2002). Additionally, people of low SES may be simultaneously more likely to live in neighborhoods with worse environmental problems and have poorer health status than those of higher SES (Galea and Vlahov 2005). It is therefore plausible – as suggested by prior research examining heterogeneity of associations by education, occupation, ethnicity, and neighborhood-level SES – that individuals of lower SES may derive more advantage from immediate surrounding green space (Agay-Shay et al. 2014; Dadvand et al. 2012a, 2012b, 2014; Dzhambov et al. 2014; Maas et al. 2009). Additional characteristics that may modify associations between green space and birth outcomes, such as degree of urbanicity of the maternal residence and season of birth, have not been adequately explored in the literature (Casey et al. 2016; Ebisu et al. 2016).

Varying results across study settings suggest that associations between the residential environment and birth outcomes may be highly specific to the particular geographic context, and additional studies of green space and birth outcomes in diverse populations and locations that facilitate inclusion of a range of environmental metrics are needed to improve our understanding of the potential influence of green areas on human health. Additionally, we are not aware of existing studies evaluating the potential influence of proximity to fresh or saltwater bodies, or 'blue space', on pregnancy outcomes. It has been suggested that blue space has restorative potential for emotional and physical well-being (Völker and Kistemann 2011, 2013; White et al. 2010), and there is some empirical evidence linking residential exposure to visible blue space to lower psychological distress (Nutsford et al. 2016), but this has not been examined in detail.

Accordingly, among 61,640 births delivered at a single hospital in Rhode Island, a region with a small coastal city with suburban and semi-rural surroundings, we evaluated the hypotheses that higher levels of residential green and blue space are associated with increased fetal growth as measured by higher birthweight and decreased risk of small for gestational age (SGA), and lower risk of preterm birth. The study location allowed us to assess green space as well as proximity to bodies of coastal and inland water, expanding what is currently known about the residential environment and pregnancy outcomes by considering multiple measures of green and blue space in a coastal geography.

# METHODS

## Study Population

Women & Infants Hospital of Rhode Island, located in the capital city of Providence, Rhode Island, is the tenth largest stand-alone obstetrical service in the U.S. with roughly 9,000 deliveries per year. Approximately 75% of births to mothers residing in Rhode Island occur at Women & Infants Hospital, making this study nearly population-based. Hospital discharge records from live births at Women & Infants Hospital from 2001–2012 were obtained from the National Perinatal Information Center (NPIC) and merged with electronic birth certificate data from the Rhode Island Department of Health (RIDOH). Electronic data were available on residential address at the time of delivery, maternal demographic indicators, infant characteristics, maternal medical history, and International Classification of Diseases, Ninth Revision (ICD-9) diagnosis and procedure codes for the mother and newborn during and after delivery. A total of 95,948 discharge records from Women & Infants Hospital were available, and of these 79,154 (82.5%) were successfully merged with state birth certificate data. Geocoded U.S. Census data from 2010 were linked to 76,590 (96.8%) of these merged records. Closer examination revealed that few discharge records were matched to birth certificate data in 2001 (prior to implementation of a modern birth records system) or between July 2004 and December 2005 (as RIDOH transitioned to a newer birth records system). Thus, we restricted our analyses to 74,165 deliveries occurring during time periods with high match rates (>88.6%, January 2002–June 2004 and January 2006–December 2012) and successfully matched to birth certificate data. We did not formally explore differences between matched and unmatched births because of the very limited data on those that did not match.

The study sample was further restricted to exclude women <18 years of age at delivery or missing data on maternal age, those with multiple births (i.e. twins, triplets) or missing data on plurality, women with residential address outside of Rhode Island or missing address data, invalid gestational ages (<22 or >44 weeks), and birthweights below 500 or above 5000 grams (g) or missing birthweight, resulting in a final sample size of 61,640 mother-infant pairs.

The study protocol was approved by the Institutional Review Boards of Brown University, Women & Infants Hospital of Rhode Island, and the Rhode Island Department of Health.

### Exposure Assessment

Residential home address at the time of delivery was obtained from the state birth certificate. Addresses were geocoded using ArcGIS for Desktop (version 10.3/10.4, ESRI, Redlands, CA) and residential surrounding green space was assessed using average Normalized Difference Vegetation Index (NDVI) values within circular buffers around the geocoded address. NDVI is designed to evaluate the global distribution of vegetation, as well as its biophysical and structural properties and spatial/temporal variations (Townsend and Justice 1995). The index is based on the reflection of visible and near-infrared light by vegetation as captured by remote sensing instruments, in this case Landsat satellite in units of 30 meter × 30 meter (m) pixels, and is calculated by the difference between near-infrared and visible radiation divided by the sum of near-infrared and visible radiation. Calculating the NDVI within a subset of a matrix of pixels (a scene), in this case a series of circular buffer areas around a residence, can be used to evaluate the amount of live vegetation, a quantitative measure of greenness, within that subset. Values of NDVI range from −1 to 1, with higher values indicating greater amounts of live vegetation (Rhew et al. 2011).

NDVI was assessed from a single Landsat 7 Scene acquired on July 31, 2002 (Scene LE70120312002212EDC00) at 30 m × 30 m spatial resolution. The particular Landsat scene was chosen as it had the least amount of cloud cover at the time of year when vegetation (greenness) would be at a maximum. The scene was downloaded from http://glovis.usgs.gov/. Image bands were calibrated to reflectance and then processed to NDVI using ENVI version 5 software (Exelis Visual Information Solutions, Boulder, CO). Pixels representing fresh and coastal waters were excluded, in order to avoid influencing the mean NDVI within circular buffers around a residence. The mean NDVI for each address was calculated within 150, 250 and 500 m of the geocoded address point using ArcGIS and customized Python scripts. Buffer radii were selected to capture greenness within the accessible neighborhood surrounding maternal residences and for consistency with prior literature (Casey et al. 2016; Dadvand et al. 2012b, 2014). NDVI values across the three buffer sizes were highly correlated (Spearman’s correlation coefficients > 0.9; see Supplemental Material, Table S2), and results are presented for the 500 m buffer; results for additional buffer sizes can be found in the Supplemental Material (see Tables S5–S8).

We additionally assessed maternal residential proximity to recreational natural environments. This proximity measure was calculated by creating a spatial matrix of distances (a raster surface) from the edge of recreation areas in the state. Using spatial overlay, each individual residence was assigned its corresponding Euclidian distance measure. In order to maintain consistency with the Landsat scene used for computing NDVI, the distance raster was generated using a spatial resolution of 30 m. Recreational areas were defined according to Statewide Comprehensive Outdoor Recreation Plan (SCORP) facilities and include athletic fields, conservation areas, fishing and boating areas, local parks/playgrounds, management areas, schools, and state parks. Nine hundred sixty-eight recreational facilities were identified within the state. Proximity was defined as within 500 meters of any recreational facility based on expectations regarding the size of the surrounding neighborhood accessible to pregnant women (Dadvand et al. 2012a) and considered as a dichotomous variable.

The same distance raster methodology was applied to measure distance to freshwater bodies greater than or equal to 5 acres in size and coastline. Freshwater bodies were identified from the Lakes and Ponds spatial data file from the Rhode Island Geographic Information System (RIGIS) and coastline from the RIGIS Municipalities spatial data file (RIGIS 2017). The ArcGIS Euclidean Distance Tool and Extract MultiValues to Points Tool were used to create distance raster files and associate the distance from each of the three distance rasters to the individual residence. Proximity to water was defined as residence within 500 meters of an inland freshwater body and within 1,000 meters of the coast. The minimum residential distance to coast observed in the data set was 300 meters, and the 1,000 meter threshold for distance to coast was selected to include more than the waterfront residences that would likely be captured by a 500 meter cut-point. An additional dichotomous variable using a 500 meter threshold was created to test a more restrictive benchmark.

For each environmental metric, we additionally considered quartiles of exposure (values of NDVI and residential distance in meters to recreational facilities, coast, and freshwater bodies) to model the change in risk with increasing levels of exposure in exposure-response sensitivity analyses.

### Outcome Assessment

Gestational age, measured in completed weeks and based on best clinical estimates that incorporate ultrasound examination, was extracted from NPIC data when available and birth certificate otherwise (n=6,931 (11.2%)). No participants were missing data on gestational age from both NPIC and birth certificates. Preterm birth was defined as birth before 37 completed weeks of gestation. Birthweight in grams was extracted from birth certificate data and considered as a continuous variable. SGA was defined as birthweight below the $10^{th}$ percentile for gestational age and sex based on 1999 and 2000 U.S. births (Oken et al. 2003).

### Covariates

Covariates assessed include maternal age, race (black, white, other), parity (0, 1, ≥2), number of prenatal visits (continuous), maternal education (some high school, high school graduate, some college, college graduate, any graduate school), marital status (married, single, other), insurance coverage (public, private, other), tobacco use during pregnancy (yes, no), gestational age at birth (continuous measure in completed weeks), NSES, town of residence, and distance to major roadways. Maternal age, education, prenatal visits, and tobacco use were extracted from birth certificate data and data on self-reported race, marital status, and insurance coverage came from the NPIC database. Tobacco use was missing for 13.7%, race was missing for 8.5%, and all other variables were missing for <5% of values (see Supplemental Material, Table S1). NSES was assessed by 6 census tract-level variables from the 2010 U.S. Census (Diez Roux et al. 2001): median household income; percent of households with interests, dividends, or rent income; percent of residents with high school diploma; percent with college degree; percent with professional occupation; and median value of owner-occupied housing units. We calculated a z-score for each of these variables and summed the scores to create a z-sum, which we used to control for potential confounding by NSES. We additionally created a variable for town of residence to reduce residual confounding by unmeasured residential factors such as access to medical care and walkability. We used 47 individual Rhode Island towns in categorization and also collapsed the towns into eight clusters defined a priori based on proximity and similarity to examine sensitivity to categorization of town in sensitivity analyses. The proportion of births by town remained fairly stable over the study period and annual number of births ranged from a minimum of roughly 10 in New Shoreham to a maximum of roughly 3,000 in Providence.

Distance to major roadways was considered as an additional environmental metric that may confound associations of interest given its correlation with the exposures of interest (Supplemental Material, Table S3) and prior evidence of an association with birth outcomes (Kingsley et al. 2016). Major roadways were defined as those with US Census feature class codes A1 (primary highway with limited access), A2 (primary road without limited access), or A3 (secondary and connecting roads). A1 and A2 roadways include interstate highways and US highways, which typically contain a mix of car and truck traffic moving at higher speeds, while A3 roadways include state highways and other major arteries and typically have fewer vehicles moving at slower average speeds. Therefore, to combine exposures from different road types using a single metric as in previous studies (Gan et al. 2010, 2014; Hart et al. 2013; Kingsley et al. 2016), we considered participants living ≤150m from an A1or A2 roadway or ≤50m from an A3 roadway as exposed and unexposed otherwise.

## Statistical Analyses

All analyses were conducted in R (R Version 3.2.1). Missing covariate data were imputed for the final sample after imposing study restrictions using Multivariate Imputation by Chained Equations (MICE Version 2.25) (Van Buuren and Groothuis-Oudshoorn 2011), assuming data missing at random conditional on the variables included in the imputation model, to create ten imputed data sets. Continuous variables were imputed using Bayesian linear regression, binary variables were imputed using logistic regression, and factors were imputed using a multinomial logit model.

In a first analysis, we tested the hypothesis that neighborhood green space was associated with lower risk of preterm birth among all births. We used logistic regression to quantify the association between a one interquartile-range (IQR) increase in NDVI and odds of preterm birth. We similarly examined residential proximity to natural environments and the potential association between blue space and preterm birth, using logistic regression to quantify the association between living within 500 meters of a recreational facility, 1,000 meters of the coast, and 500 meters of a freshwater body and the odds of preterm birth. In sensitivity analyses we evaluated associations using a 500 meter cut-point for coastal proximity.

In a second set of analyses, we used the same approach to evaluate associations between the same exposure variables and fetal growth among term births, applying linear regression to model the difference in birthweight and logistic regression to model the log odds of being born SGA.

We carried out the following incremental adjustment for all analyses to describe the confounding effects of individual and contextual socioeconomic characteristics: 1) adjusting first for mother’s age, number of prenatal visits, mother’s education, race, health insurance, marital status, parity, and tobacco use; 2) next, adding adjustment for neighborhood socioeconomic status through NSES z-score; and, 3) additionally adjusting for town of residence with a robust standard error to account for correlation of standard errors within a town. Gestational age at birth (in weeks) as a continuous variable was also included in birthweight models. Fully-adjusted models for both blue and green space included all aforementioned covariates and mutual adjustment for environmental metrics (NDVI and proximity to recreational facilities, coastline, freshwater, and roadways). Adjusting for NSES and town of residence had a material effect on some of the results, and there is uncertainty as to the optimal amount of adjustment to minimize confounding bias without attenuating a causal effect of the spatial attributes of interest. Accordingly, we present findings from models with each level of incremental adjustment.

As a sensitivity analysis, we modeled quartiles of each exposure to evaluate the shape of the exposure-response curve in preterm birth and birthweight models and estimate the p-value for linear trend.

We performed stratified analyses to assess whether the associations between green and blue space metrics and birth outcomes differed by levels of neighborhood socioeconomic status, race, maternal education, residential urbanicity (measured by population density), and season of birth. To evaluate differences across subgroups defined by neighborhood SES, race, education, urbanicity, and season of birth, we stratified separate models by: tertile of NSES z-score; white or other race; urban or rural residence; and birth in winter (December 21–March 20), spring (March 21–June 20), summer (June 21–September 20), or fall (September 21–December 20). Census-tract level data on population density was used to measure urbanicity. Areas were defined as urban if the population density was greater than or equal to 1,000 persons per square mile, and rural otherwise. Stratified models were adjusted for individual-level covariates as listed in Table 4; additionally adjusting for neighborhood-level SES did not notably change patterns of heterogeneity and as such NSES adjustment was not included in stratified models. To evaluate differences by strata in all models, a relaxed criterion of $p<0.10$ was used to identify presence of statistically significant heterogeneity of associations (Rothman et al. 2008)

## RESULTS

The study population of 61,640 births reflects the population of Rhode Island, with 65% of mothers self-identifying as white, 8% as black, and 27% as American Indian, Filipino, Hispanic, other Asian, or not specified (Table 1). The mean (standard deviation) age of mothers was 29 (5.9) years. More than half of women had completed at least some college education, were married, and were covered by private insurance. The average gestational age at birth was 39 weeks, and 8.1% (n=5,007) of infants were born preterm. The mean (SD) birthweight was 3,341 (563) grams among all births, and 3,426 (459) grams among term births.

NDVI varied across the state, with lower values in highly urban areas and higher values in more rural areas (Figure 1). The average NDVI in a 500 meter buffer was 0.44. NDVI values across different buffer sizes were very highly correlated with each other, highly correlated with indicators of neighborhood socioeconomic status, moderately correlated with distance to the coast, and weakly correlated with distance to freshwater (Supplemental Material, Tables S2 & S3). The majority (65%) of women lived within 500 meters of a recreational facility, 30% lived within 500 meters of freshwater, and 20% lived within 1,000 meters of the coast (Table 1).

We first evaluated associations between green and blue space and risk of preterm birth. In models adjusted for patient characteristics and individual-level markers of SES (mother's age, number of prenatal visits, tobacco use, parity, education, race, health insurance, and marital status), an interquartile range (IQR) increase in NDVI was unexpectedly associated with a 9% (95% CI 3%, 16%) *higher* odds of preterm birth (Table 2). Upon further adjustment for neighborhood SES, an IQR increase in NDVI was associated with a 12% (95% CI 4%, 20%) higher odds of preterm birth. However, this association was eliminated after additional adjustment for town of residence. Living close to recreational facilities was associated with a 7% (95% CI 1%, 13%) lower risk of preterm birth in models adjusted for individual and neighborhood-level markers of SES, but results were attenuated toward the null and no longer statistically significant when further adjusted for town of residence and when fully adjusted for all environmental metrics. Neither residential distance to freshwater nor coast were associated with risk of preterm birth.

We next evaluated associations between residential green and blue space and term birthweight. In unadjusted models, we found that NDVI and proximity to the coast were associated with higher birthweight while living close to recreational facilities was unexpectedly associated with lower birthweight (Table 3). The association between NDVI and birthweight was substantially attenuated by individual-level adjustment and eliminated with further adjusted for NSES. The associations with proximity to recreational facilities or the coast were eliminated after adjustment for patient demographics and markers of individual-level socioeconomic status. Living within 500 meters of freshwater was associated with a higher birthweight of 10.1 grams (95% CI: 2.0, 18.2) robust to degree of adjustment. Results for NDVI, recreational facilities, and coastal proximity were qualitatively similar when assessing risk of SGA rather than birthweight. However, we did not find evidence of an association between proximity to freshwater and risk of SGA in any model.

We examined exposure-response relationships and confirmed an association between increasing quartiles of NDVI and higher risk of preterm birth as well as evidence of lower term birthweight with greater distance to freshwater, with statistically significant linear trends in both relationships (Supplemental Table S4). Results were not materially different in sensitivity analyses considering residential NDVI within 150 and 250 m buffers instead of 500 m (Supplemental Material, Tables S5–S8), and did not change when using a clustered rather than single town-level variable for town of residence.

We assessed whether associations between residential green and blue space and birth outcomes adjusted for patient characteristics and individual markers of SES varied by categories of neighborhood SES, race, education, population density, and season of birth (Table 4). We found some evidence of heterogeneity in green space associations with preterm birth for maternal education and population density, with the strongest associations between NDVI and higher risk of preterm birth observed among mothers with less than a college education and those living in urban areas. Importantly, there was no subgroup among which NDVI was associated with lower risk of preterm birth. The association between NDVI and birthweight appeared to vary across strata of neighborhood SES and maternal race, with statistically significant increases in mean birthweight of roughly 12–13 grams per IQR increase in NDVI observed among mothers in the upper tertile of neighborhood SES and white women, and nonsignificant negative associations observed among mothers in the lower tertile of neighborhood SES and non-white women. We similarly found a 12% decrease (95% CI 6%, 18%) in the odds of SGA per IQR increase in NDVI among white women, but did not find significant associations across other demographic characteristics. Results for recreational facilities were largely null (Supplemental Material, Table S9).

We found lower odds of preterm birth associated with residential proximity to freshwater among those in the highest NSES tertile, and borderline significant evidence for heterogeneity of associations suggesting stronger gains in birthweight associated with proximity to a freshwater body among white women and women living in the wealthiest neighborhoods (Table 4). Stratified results for proximity to coast did not indicate patterns different from the main effects analyses (Supplemental Material, Table S10).

## DISCUSSION

This study is among the first to report on the impact of residential proximity to both green and blue spaces on pregnancy outcomes in a coastal location. We found that in unadjusted models NDVI was associated with a slightly lower risk of preterm birth, higher birthweight, and lower risk of SGA. However, after adjustment for patient demographics and markers of individual SES, higher NDVI was associated with higher risk of preterm birth and a small, but still statistically significant, increase birthweight and decrease in risk of SGA. Further adjustment for neighborhood SES or town of residence tended to eliminate these associations. We also found that living close to freshwater was associated with higher birthweight, and that this association was robust to adjustment for potential confounding by individual and neighborhood characteristics. Residential proximity to freshwater was not associated with risk of preterm birth or SGA, and proximity to coast was not associated with any outcome.

Overall, our findings do not support the hypothesized protective association between green space as assessed by NDVI and preterm birth. Prior studies evaluating the association between NDVI and risk of preterm birth or length of gestation have been equivocal, with some (Casey et al. 2016; Hystad et al. 2014) but not all (Agay-Shay et al. 2014; Dadvand et al. 2012a, 2012b; Grazuleviciene et al. 2015) studies reporting a reduced risk. A study in Lithuania found lower risk of preterm birth associated with residential proximity to urban parks (Grazuleviciene et al. 2015). Similarly, we found a protective association between proximity to recreational facilities and preterm birth after adjustment for multiple indicators of individual and neighborhood SES, but not when additionally accounting for town of residence.

Stratification according to categories of neighborhood SES, education, race, population density, and season of birth did not provide any evidence to support the hypothesis that higher NDVI is associated with decreased risk of preterm birth. This is counter to evidence of green space benefits strongest among more disadvantaged social groups (Banay et al. 2017). Our finding of a harmful association between NDVI and risk of preterm birth with adjustment for individual- and neighborhood-level characteristics is counterintuitive and not readily explained by subgroup patterns. This finding could be attributable to factors associated with rural versus urban lifestyles, such as distance from medical facilities or community centers with health promotion programs in rural areas or higher levels of exposure to other environmental risk factors such as pesticides or ozone in greener, rural locations. However, stratified results for risk of preterm birth were strongest in urban areas, which oppose such explanations.

Our modestly protective results for NDVI and markers of fetal growth, robust to adjustment for individual but not neighborhood socioeconomic characteristics, were weaker than expected based on prior studies. Green space has been previously associated with higher mean birthweight and lower risk of low birthweight and SGA in European and Canadian populations, although again results have been of varying statistical significance (Agay-Shay et al. 2014; Dadvand et al. 2012b, 2014; Dzhambov et al. 2014; Hystad et al. 2014; Markevych et al. 2014). For example, studies in the UK and Spain found that in fully adjusted models an IQR increase in residential greenness was associated with a statistically significant higher birthweight of approximately 15–30 g (Dadvand et al. 2012b, 2014). However, findings in the United States have largely been more modest and closer to our results, reporting increased term birthweight of 2–6 g (Cusack et al. 2017; Ebisu et al. 2016; Laurent et al. 2013) and an 8% decreased risk of low birthweight (Ebisu et al. 2016) per IQR increase in NDVI. We chose to model term SGA as opposed to low birthweight since the latter measure conflates suboptimal fetal growth with preterm deliveries that had normal growth trajectories (Savitz et al. 2002). Existing studies of the amount of residential surrounding green space and SGA have reported a mix of null (Cusack et al. 2017) and protective findings (Casey et al. 2016; Donovan et al. 2011). Two European studies that evaluated proximity to green areas in addition to NDVI reported no association between proximity and birthweight (Dadvand et al. 2012a; Grazuleviciene et al. 2015), while one found an 18 g increase in mean birthweight associated with residence within 300 meters of a major green space (Agay-Shay et al. 2014). However, these studies measured proximity to city parks or green areas larger than 5,000 square meters, which differs from our definition of recreational facilities, making direct comparison of our results challenging.

Stratification by NSES and race suggest that associations between green space and fetal growth may be strongest among white women and women in the wealthiest neighborhoods. Benefits specific to wealthier individuals have not been reported in prior literature, though in the UK Dadvand et al. (2014) did similarly find significant associations between NDVI and birthweight only for white British and not Pakistani participants (Dadvand et al. 2014). Conversely, several studies suggest that the beneficial effects of greenspace on fetal growth may be strongest among births to women of lower socioeconomic status (Cusack et al. 2017; Dadvand et al. 2012a, 2014), lower education levels (Cusack et al. 2017; Dadvand et al. 2012b; Dzhambov et al. 2014; Markevych et al. 2014) and in urban settings (Casey et al.

2016). Overall, our findings for fetal growth do not confirm these patterns, and inconsistencies suggest that the relationship between socioeconomic indicators, residential green space, and birth outcomes varies considerably by context and may not be generalizable across different locations.

Our results demonstrate substantial confounding by SES markers, taking individual characteristics and SES, neighborhood SES, and specific town of residence into consideration. Socioeconomic status is a well-established predictor of birth outcomes (Andersen and Mortensen 2006; Racape et al. 2016; Weck et al. 2008). Markers of neighborhood SES were strongly correlated with green space in this study, and prior research has shown that affluent individuals are more likely to live in neighborhoods with more grass, trees, and other vegetation (Kihal-Talantikite et al. 2013). The significance, and in some cases the magnitude, of our findings varied with incremental adjustment for measures of socioeconomic status. This variation raises uncertainty regarding the ideal degree of adjustment to balance the likely strong confounding by lifestyle and contextual factors against the potential for overadjustment for strongly correlated socioeconomic and environmental variables or variables possibly on the causal pathway between exposures and outcomes of interest such as neighborhood-level income, occupation, and education measures that may be dictated by environmental characteristics (Chee et al. 2015; Cole et al. 2017). We posit that fully adjusted, attenuated associations in our study represent the most complete control of residual confounding by environmental and lifestyle factors related to the latent construct of SES, but acknowledge the possibility that adjustment for these attributes risks overadjustment. Additional adjustment for town of residence was intended to capture health-relevant attributes that were not otherwise known from the available data, but this adjustment may also limit exposure variation and account for the observed attenuation in associations.

Other studies of green space and birth outcomes similarly reported that associations were weakened after adjustment for multiple measures of socioeconomic status. Dadvand et al. (2014) found comparable patterns in the Born in Bradford pregnancy cohort in the UK, with estimates of approximately 78–97 g higher birthweight per IQR increase in green space reduced to 13–16 g after adjustment for indicators of individual and neighborhood SES (Dadvand et al. 2014), broadly similar to the strong impact of adjustment on associations with preterm birth, SGA, and term birthweight in US studies (Casey et al. 2016; Cusack et al. 2017; Ebisu et al. 2016; Laurent et al. 2013). Taken together, these findings highlight the need for further research designed to elucidate causal pathways and evaluate the appropriate level of confounding control to address the substantial influence of SES on neighborhood environmental characteristics and birth outcomes without removing any true effect of the exposure of interest.

We hypothesized a protective association between blue space and birth outcomes but did not find convincing evidence of an association between living in close proximity to the coast or to freshwater and altered risk of preterm birth. However, living near freshwater was associated with a slightly higher birthweight, particularly among individuals living in higher SES neighborhoods and white women. These novel results may reflect increased propensity to use rivers and other freshwater areas for physical activity or stress relief by more affluent individuals, but this hypothesis could not be assessed in these analyses. This is, to our knowledge, the first study to evaluate the possible effects of blue space on pregnancy outcomes, and so we are unable to compare our findings to existing literature. Given nascent evidence of psychosocial benefits (Nutsford et al. 2016; Völker and Kistemann 2013; White et al. 2010) as well as the potential for heat reduction, decreased traffic, air, and noise pollution, and increased physical activity in residential areas close to bodies of water, additional studies of blue space and pregnancy outcomes are warranted.

Our study was limited by the use of maternal address at the time of delivery derived from birth certificates, precluding consideration of residential mobility during pregnancy. We anticipate that any resulting exposure misclassification would be nondifferential with respect to birth outcomes and would generally bias associations toward the null. Time spent at work and outside the home is also not accounted for in our analyses, but our exposure assessment strategy was designed to investigate the health benefits of markers of the residential built environment and not of green or blue space outside of women's neighborhoods or actual use of green and blue space. Further, births between July 2004 and December 2005 were excluded due to low birth certificate and hospital discharge record match rates. However, we do not have reason to believe that births during these years were systematically different from the study population with respect to exposures or outcomes of interest and do not expect this to be an important source of selection bias.

While the satellite NDVI measures offer objective, standardized classifications of green space that can be compared across studies, we were unable to differentiate between types of vegetation and assess whether impacts of green space depend on the predominant type of surrounding vegetation (e.g. tree cover, grassy areas, etc.). Further, we used a single Landsat scene for NDVI calculation, which does not take into account changes in green space across the study period or fluctuations by season or across trimester of pregnancy and is a limitation of our exposure assessment. While patterns may differ across study contexts, prior research on green space and birth outcomes found similar spatial patterns of NDVI across seasons (Dadvand et al. 2012b, 2014; Hystad et al. 2014) and high correlation between trimester-specific and pregnancy-average NDVI levels (Cusack et al. 2017). We acknowledge that the potential temporal mismatch between assessment of exposure, outcomes, and neighborhood-level covariates given the data sources employed is a possible source of misclassification, but expect minimal change in the rank order of values of these variables over the study period.

Proximity to recreational areas and blue space was based on straight-line distance and did not take into account proximity via roadways or walking paths, or other forms of network connectivity, and may not fully capture the accessibility of these features. We chose to use dichotomous indicators as our primary measure of proximity as opposed to continuous distance since our aim was to identify whether green and blue spaces within typically-reasonable walking distance of the residential neighborhood were meaningful for birth outcomes. We selected distance cut-points based on expectations regarding the average walking patterns and speeds of pregnant women informed by prior research by Dadvand et al. (2012a), but note that our use of 500 m. in Euclidian distance differs from the 500 meter network buffer used in their research (Dadvand et al. 2012a). Studies of associations between proximity to green areas and birth outcomes, to our knowledge, have not previously used distance measures other than network buffers, which are needed to explore whether alternate measures of proximity are meaningful for health in pregnancy.

Rhode Island is a coastal state in leafy New England with relatively small urban and largely suburban and semi-rural areas. As such, deprivation from green space is likely relatively less common in this setting versus in larger cities, in other regions of the US, or the typically high population density cities of Europe, making green space particularly difficult to generalize across settings since its impact may truly differ with varied demographic distributions and levels of surrounding greenness. We were unable to adjust our analyses for several behavioral and environmental confounders such as maternal body mass index and neighborhood safety, and were only able to adjust for a rudimentary measure of maternal tobacco use, and it is possible that these factors influenced our results. As previously discussed, however, we adjusted for a number of individual and contextual covariates to address to the fullest extent possible residual confounding. Finally, we were unable to assess actual use of green or blue space by study participants, and further research into whether effects differ by factors such as neighborhood walkability, amount of time spent outdoors, and type of use would be important in disaggregating meaningful pathways such as altered levels of physical activity or stress reduction through which green and blue space may affect health.

## CONCLUSIONS

The findings from this study do not support the hypothesis that amount of surrounding residential green space is associated with reduced risk of preterm birth. The very small association between NDVI and preterm birth observed in unadjusted analyses disappears completely, and sometimes reverses to harmful associations, upon adjustment for potential confounders. We found evidence of a small protective association between residential proximity to recreational facilities and preterm birth, and between NDVI and fetal growth, but results were sensitive to adjustment for contextual covariates. These findings raise questions about the optimal degree of adjustment for confounding by socioeconomic factors that should be explored in other studies of the residential environment and birth outcomes. Our results similarly fail to support the presence of an association between living very near the coast and beneficial birth outcomes. We did find that living near a freshwater body was associated with higher birthweight even after adjusting for potential confounders. This result is novel and bears further investigation in other settings and populations.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Abbreviations

| | |
|---|---|
| **NDVI** | Normalized Difference Vegetation Index |
| **PTB** | preterm birth |
| **SGA** | small for gestational age |
| **SES** | socioeconomic status |
| **NSES** | neighborhood socioeconomic status |
| **NPIC** | National Perinatal Information Center |
| **RIDOH** | Rhode Island Department of Health |
| **IQR** | interquartile range |

## References

Agay-Shay K, Peled A, Crespo AV, Peretz C, Amitai Y, Linn S, et al. Green spaces and adverse pregnancy outcomes. Occup Environ Med. 2014; 71:562–9. DOI: 10.1136/oemed-2013-101961 [PubMed: 24759971]

Alcock I, White MP, Wheeler BW, Fleming LE, Depledge MH. Longitudinal effects on mental health of moving to greener and less green urban areas. Environ Sci Technol. 2014; 48:1247–1255. DOI: 10.1021/es403688w [PubMed: 24320055]

Andersen AMN, Mortensen LH. Socioeconomic inequality in birth outcomes: What do the indicators tell us, and where do we find the data? CMAJ. 2006; 174:1429–1430. DOI: 10.1503/cmaj.060349 [PubMed: 16682710]

Banay RF, Bezold CP, James P, Hart JE, Laden F. Residential greenness: current perspectives on its impact on maternal health and pregnancy outcomes. Int J Womens Health. 2017; 9:133–144. DOI: 10.2147/IJWH.S125358 [PubMed: 28280395]

Bowler DE, Buyung-Ali LM, Knight TM, Pullin AS. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health. 2010; 10:456.doi: 10.1186/1471-2458-10-456 [PubMed: 20684754]

Casey JA, James P, Rudolph KE, Chih-Da W, Schwartz BS. Greenness and birth outcomes in a range of Pennsylvania communities. Int J Environ Res Public Health. 2016; 13doi: 10.3390/ijerph13030311

Chee A, Lee K, Jordan HC, Horsley J. Value of urban green spaces in promoting healthy living and wellbeing: Prospects for planning. Risk Manag Healthc Policy. 2015; 8:131–137. [PubMed: 26347082]

Cole HVS, Lamarca MG, Connolly JJT, Anguelovski I, Hospital I. Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. Joiurnal Epidemilogy Community Heal. 2017; 71:1118–1121. DOI: 10.1136/jech-2017-209201

Cusack L, Larkin A, Carozza S, Hystad P. Associations between residential greenness and birth outcomes across Texas. Environ Res. 2017; 152:88–95. DOI: 10.1016/j.envres.2016.10.003 [PubMed: 27743971]

Dadvand P, de Nazelle A, Figueras F, Basagana X, Su J, Amoly E, et al. Green space, health inequality and pregnancy. Environ Int. 2012a; 40:110–115. DOI: 10.1016/j.envint.2011.07.004 [PubMed: 21824657]

Dadvand P, Sunyer J, Basagana X, Ballester F, Lertxundi A, Fernandez-Somoano A, et al. Surrounding greenness and pregnancy outcomes in four Spanish birth cohorts. Environ Health Perspect. 2012b; 120:1481–1487. DOI: 10.1289/ehp.1205244 [PubMed: 22899599]

Dadvand P, Wright J, Martinez D, Basagana X, McEachan RRC, Cirach M, et al. Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status. Environ Int. 2014; 71:101–108. DOI: 10.1016/j.envint.2014.06.010 [PubMed: 24997306]

Diez Roux A, Merkin SS, Arnett D, Chambless L, Massing M, Nieto J, et al. Neighborhood of residence and incidence of coronary heart disease. N Engl J Med. 2001; 345:99–106. [PubMed: 11450679]

Donovan GH, Michael YL, Butry DT, Sullivan AD, Chase JM. Urban trees and the risk of poor birth outcomes. Health Place. 2011; 17:390–393. DOI: 10.1016/j.healthplace.2010.11.004 [PubMed: 21106432]

Dzhambov AM, Dimitrova DD, Dimitrakova ED. Association between residential greenness and birth weight: Systematic review and meta-analysis. Urban For Urban Green. 2014; 13:621–629. DOI: 10.1016/j.ufug.2014.09.004

Ebisu K, Holford TR, Bell ML. Association between greenness, urbanicity, and birth weight. Sci Total Environ. 2016; 542:750–756. DOI: 10.1016/j.scitotenv.2015.10.111 [PubMed: 26546769]

Galea S, Vlahov D. Urban health: Evidence, challenges, and directions. Annu Rev Public Health. 2005; 26:341–365. DOI: 10.1146/annurev.publhealth.26.021304.144708 [PubMed: 15760293]

Gan WQ, Allen RW, Brauer M, Davies HW, Mancini GBJ, Lear SA. Long-term exposure to traffic-related air pollution and progression of carotid artery atherosclerosis: a prospective cohort study. BMJ Open. 2014; 4:e004743.doi: 10.1136/bmjopen-2013-004743

Gan WQ, Tamburic L, Davies HW, Demers PA, Koehoorn M, Brauer M. Changes in residential proximity to road traffic and the risk of death from coronary heart disease. Epidemiology. 2010; 21:642–9. DOI: 10.1097/EDE.0b013e3181e89f19 [PubMed: 20585255]

Gascon M, Mas MT, Martínez D, Dadvand P, Forns J, Plasència A, et al. Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. Int J Environ Res Public Health. 2015; 12:4354–4379. DOI: 10.3390/ijerph120404354 [PubMed: 25913182]

Grazuleviciene R, Danileviciute A, Dedele A, Vencloviene J, Andrusaityte S, Uzdanaviciute I, et al. Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. Int J Hyg Environ Health. 2015; 218:358–365. DOI: 10.1016/j.ijheh.2015.02.004 [PubMed: 25757723]

Hart JE, Rimm EB, Rexrode KM, Laden F. Changes in traffic exposure and the risk of incident myocardial infarction and all-cause mortality. Epidemiology. 2013; 24:734–42. DOI: 10.1097/EDE.0b013e31829d5dae [PubMed: 23877047]

Hystad P, Davies HW, Frank L, Van Loon J, Gehring U, Tamburic L, et al. Residential greenness and birth outcomes: Evaluating the influence of spatially correlated built-environment factors. Environ Health Perspect. 2014; 122:1095–1102. DOI: 10.1289/ehp.1308049 [PubMed: 25014041]

James P, Hart JE, Banay RF, Laden F. Exposure to greenness and mortality in a nationwide prospective cohort study of women. Environ Health Perspect. 2015; 1344:1344–1352. DOI: 10.1289/ehp.1510363

Kihal-Talantikite W, Padilla CM, Lalloué B, Gelormini M, Zmirou-Navier D, Deguen SS. Green space, social inequalities and neonatal mortality in France. BMC Pregnancy Childbirth. 2013; 13:191.doi: 10.1186/1471-2393-13-191 [PubMed: 24139283]

Kingsley SL, Eliot MN, Whitsel EA, Huang YT, Kelsey KT, Marsit CJ, et al. Maternal residential proximity to major roadways, birth weight, and placental DNA methylation. Environ Int. 2016; 92–93:43–49. DOI: 10.1016/j.envint.2016.03.020

Laurent O, Wu J, Li L, Milesi C. Green spaces and pregnancy outcomes in Southern California. Health Place. 2013; 24:190–5. DOI: 10.1016/j.healthplace.2013.09.016 [PubMed: 24140704]

Lee ACK, Maheswaran R. The health benefits of urban green spaces: A review of the evidence. J Public Health (Bangkok). 2011; 33:212–222. DOI: 10.1093/pubmed/fdq068

Maas J. Vitamin G: Green environments - Healthy environments. 2008

Maas J, Verheij RA, de Vries S, Spreeuwenberg P, Schellevis FG, Groenewegen PP. Morbidity is related to a green living environment. J Epidemiol Community Health. 2009; 63:967–973. DOI: 10.1136/jech.2008.079038 [PubMed: 19833605]

Maas J, Verheij RA, Groenewegen PP, de Vries S, Spreeuwenberg P. Green space, urbanity, and health: how strong is the relation? J Epidemiol Community Health. 2006; 60:587–592. DOI: 10.1136/jech.2005.043125 [PubMed: 16790830]

Markevych I, Fuertes E, Tiesler CMT, Birk M, Bauer CP, Koletzko S, et al. Surrounding greenness and birth weight: Results from the GINIplus and LISAplus birth cohorts in Munich. Health Place. 2014; 26:39–46. DOI: 10.1016/j.healthplace.2013.12.001 [PubMed: 24361636]

Nutsford D, Pearson AL, Kingham S, Reitsma F. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. Health Place. 2016; 39:70–78. DOI: 10.1016/j.healthplace.2016.03.002 [PubMed: 26974233]

Oken E, Kleinman KP, Rich-Edwards J, Gillman MW. A nearly continuous measure of birth weight for gestational age using a United States national reference. BMC Pediatr. 2003; 3:6.doi: 10.1186/1471-2431-3-6 [PubMed: 12848901]

Racape J, Schoenborn C, Sow M, Alexander S, De Spiegelaere M. Are all immigrant mothers really at risk of low birth weight and perinatal mortality? The crucial role of socio-economic status. BMC Pregnancy Childbirth. 2016; 16:75.doi: 10.1186/s12884-016-0860-9 [PubMed: 27059448]

Rhew IC, Vander Stoep A, Kearney A, Smith NL, Dunbar MD. Validation of the Normalized Difference Vegetation Index as a measure of neighborhood greenness. Ann Epidemiol. 2011; 21:946–952. DOI: 10.1016/j.annepidem.2011.09.001 [PubMed: 21982129]

RIGIS. Rhode Island Geographic Information System (RIGIS) Data Distribution System. 2017

Rothman, KJ., Greenland, S., Lash, TL. Modern Epidemiology. 3rd. Lippincott Williams & Wilkins; 2008.

Savitz DA, Hertz-picciotto I, Poole C, Olshan AF. Epidemiologic measures of the course and outcome of pregnancy. Epidemiol Rev. 2002; 24:91–101. DOI: 10.1093/epirev/mxf006 [PubMed: 12762085]

Schwanen T, Dijst M, Dieleman FM. A microlevel analysis of residential context and travel time. Environ Plan A. 2002; 34:1487–1507.

Townsend JRG, Justice CO. Spatial variability of images and the monitoring of changes in the Normalized Difference Vegetation Index. Int J Remote Sens. 1995; 16:2187–2195.

Van Buuren S, Groothuis-Oudshoorn K. Multivariate Imputation by Chained Equations. J Stat Softw. 2011; 45:1–67. DOI: 10.1177/0962280206074463

Villeneuve PJ, Jerrett MG, Su J, Burnett RT, Chen H, Wheeler AJ, et al. A cohort study relating urban green space with mortality in Ontario, Canada. Environ Res. 2012; 115:51–58. DOI: 10.1016/j.envres.2012.03.003 [PubMed: 22483437]

Völker S, Kistemann T. I'm always entirely happy when I'm here!" Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. Soc Sci Med. 2013; 91:141–152. DOI: 10.1016/j.socscimed.2013.04.016 [PubMed: 23672961]

Völker S, Kistemann T. The impact of blue space on human health and well-being - Salutogenetic health effects of inland surface waters: A review. Int J Hyg Environ Health. 2011; 214:449–460. DOI: 10.1016/j.ijheh.2011.05.001 [PubMed: 21665536]

Weck RL, Paulose T, Flaws JA. Impact of environmental factors and poverty on pregnancy outcomes. Clin Obstet Gynecol. 2008; 51:349–359. DOI: 10.1097/GRF.0b013e31816f276e [PubMed: 18463465]

White M, Smith A, Humphryes K, Pahl S, Snelling D, Depledge M. Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. J Environ Psychol. 2010; 30:482–493. DOI: 10.1016/j.jenvp.2010.04.004

Wilker EH, Wu C-D, McNeely E, Mostofsky E, Spengler J, Wellenius GA, et al. Green space and mortality following ischemic stroke. Environ Res. 2014; 133:42–48. DOI: 10.1016/j.envres.2014.05.005 [PubMed: 24906067]

## Highlights

- Influence of residential greenness on birth outcomes in Rhode Island is examined.
- Proximity to bodies of water, or ‘blue space’, is additionally explored.
- Findings do not provide convincing evidence of protection against preterm birth.
- Living near a freshwater body is associated with slightly higher birthweight.
- The optimal level of adjustment for socioeconomic factors merits further research.

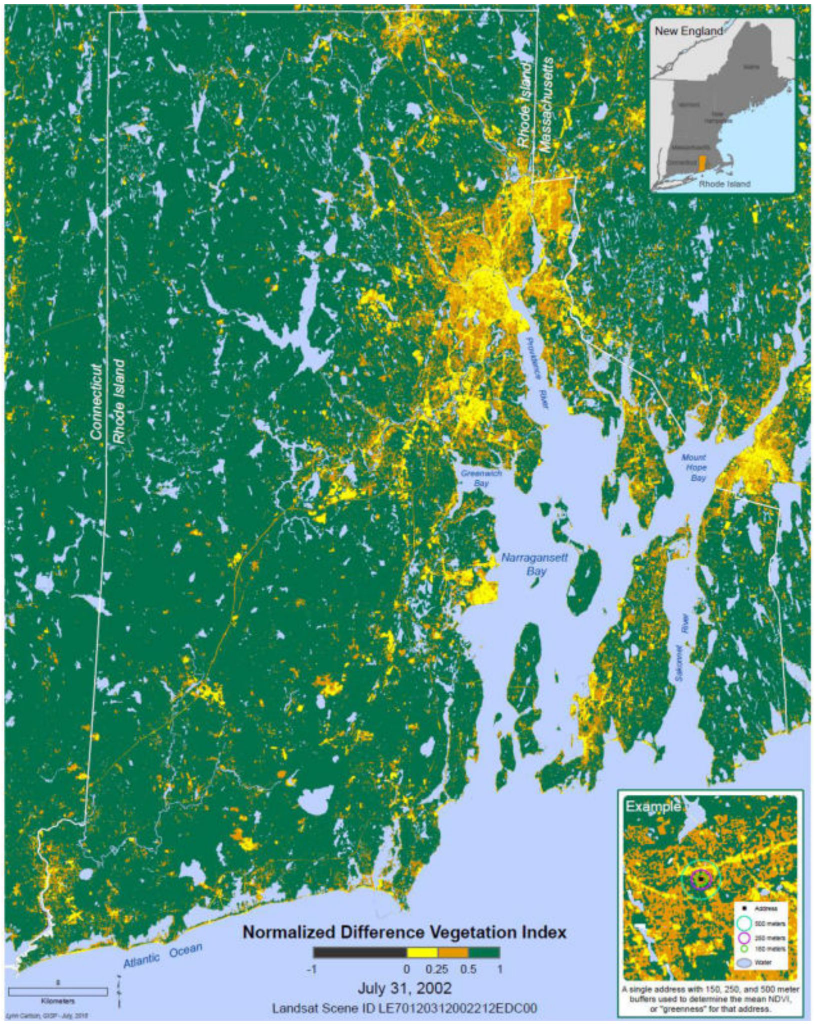


**Figure 1.**

Distribution of green space measured by Normalized Difference Vegetation Index (NDVI), Rhode Island, July 2002

**Table 1**

Characteristics of 61,640 live births and 56,633 term live births born at Women and Infants Hospital of Rhode Island between 2002 and 2012.

| Variables | Mean ± SD or N (%)[a] | |
|---|---|---|
| | **All births (n= 61,640)** | **Term births (n=56,633)** |
| ***Infant Characteristics*** | | |
| **Gestational Age, weeks** | 38.7 ± 2.0 | 39.1 ± 1.1 |
| **Preterm birth** | 5,007 (8.1) | |
| **Birthweight, g** | 3,341 ± 563 | 3,426 ± 459 |
| **Small for gestational age** | 5,442 (8.8) | 4,810 (8.5) |
| ***Maternal Characteristics*** | | |
| **Parity** | | |
| 0 | 25,805 (42.9) | 23,603 (42.7) |
| 1 | 20,209 (33.6) | 18,797 (34.0) |
| ≥2 | 14,142 (23.5) | 12,898 (23.3) |
| **Number of Prenatal visits** | 13.1 ± 4.9 | 13.2 ± 4.8 |
| **Age, years** | 29.0 ± 5.9 | 29.0 ± 5.8 |
| **Ethnicity** | | |
| Black | 4,706 (8.3) | 4,228 (8.2) |
| White | 36,510 (64.7) | 33,657 (64.9) |
| Other[b] | 15,226 (27.0) | 13,967 (26.9) |
| **Education** | | |
| Some High School or less | 7,609 (12.8) | 6,861 (12.6) |
| Completed High School | 15,932 (26.8) | 14,609 (26.7) |
| Some College | 11,027 (18.6) | 10,149 (18.6) |
| Completed College | 14,785 (24.9) | 13,695 (25.1) |
| Any Graduate School | 10,010 (16.9) | 9,303 (17.0) |
| **Marital status** | | |
| Married | 38,347 (62.6) | 35,440 (63.0) |
| Single | 21,139 (34.5) | 19,249 (34.2) |
| Other[c] | 1,793 (2.9) | 1,607 (2.9) |
| **Insurance coverage**[d] | | |
| Private | 34,220 (55.9) | 31,628 (56.2) |
| Public | 24,843 (40.6) | 22,668 (40.3) |
| Other | 2,185 (3.6) | 1,973 (3.5) |
| **Tobacco use in pregnancy** | 3,529 (6.6) | 3,097 (6.3) |
| ***Neighborhood Characteristics*** | | |
| **Mean household income** | 53,330 ± 23,004 | 53,420 ± 23,086 |
| **Percent households receiving rent income** | 21.5 (10.2) | 21.5 (10.2) |
| **Percent adults with high school diploma** | 79.6 (13.3) | 79.7 (13.3) |
| **Percent adults with college degree** | 33.7 (16.9) | 33.8 (16.9) |

| Variables | Mean ± SD or N (%)[a] | |
|---|---|---|
| | All births (n= 61,640) | Term births (n=56,633) |
| **Percent adults in professional occupation** | 32.4 (14.7) | 32.5 (14.8) |
| **Average household size of occupied units** | 2.6 ± 0.4 | 2.6 ± 0.4 |
| ***Built Environment Characteristics*** | | |
| **NDVI (500 meter buffer)** | 0.44 ± 0.15 | 0.44 ± 0.15 |
| **Distance to recreational facilities (meters)**[e] | 385 (240, 622) | 386 (241, 622) |
| **Residence within 500 m. of recreational facility** | 39,816 (64.6) | 36,571 (64.6) |
| **Distance to coast (meters)** | 2,762 (1,207, 5388)[e] | 2,766 (1,207, 5,392)[e] |
| **Residence within 1,000 m. of coast** | 12,450 (20.2) | 11,445 (20.2) |
| **Residence within 500 m. of coast** | 6,092 (9.9) | 5,606 (9.9) |
| **Distance to freshwater (meters)** | 768 (431, 1,236)[e] | 768 (431, 1236)[e] |
| **Residence within 500 m. of freshwater** | 18,712 (30.4) | 17,213 (30.4) |
| **Residence near A1 or A2 roadway**[f] | 5,774 (9.4) | 5,293 (9.3) |

[a]Frequencies may not sum to full sample size due to missing data;

[b]Includes American Indian, Filipino, Hispanic, Other Asian, and Other (not specified);

[c]Includes divorced, separated, widowed, and unknown;

[d]Private: Blue Cross/Blue Shield, Commercial insurance, and HMO coverage; Public: Medicaid or Medicaid/HMO; Other: Medicare, Champus, Self-coverage, Other coverage, Coverage unknown;

[e]Values reported as median (p25, p75) for non-normally distributed distance variables;

[f]Residence near roadway defined as within 150 m of an A1 or A2 roadway or within 50 m of an A3 roadway.

## Table 2

Association between markers of green and blue space and relative odds of preterm birth (95% confidence intervals) among 61,640 births in Rhode Island.

| | Unadjusted | +adjustment for patient demographics and markers of individual SES[b] | + adjustment for markers of neighborhood SES[c] | +adjustment for town of residence[d] | + adjustment for all other available environmental variables[e] |
|---|---|---|---|---|---|
| **NDVI (500 m buffer)**[a] | 0.96 (0.92, 1.01) | 1.09 (1.03, 1.16) ** | 1.12 (1.04, 1.20) ** | 1.02 (0.92, 1.13) | 1.01 (0.91, 1.13) |
| **Proximity to recreational facilities (500 m)** | 1.01 (0.95, 1.07) | 0.93 (0.87, 0.996) * | 0.93 (0.87, 0.99) * | 0.97 (0.91, 1.05) | 1.00 (0.98, 1.01) |
| **Proximity to coast (1000m)** | 0.99 (0.92, 1.07) | 1.02 (0.95, 1.10) | 1.02 (0.94, 1.09) | 1.02 (0.93, 1.12) | 1.00 (0.98, 1.03) |
| **Proximity to coast (500m)** | 0.98 (0.89, 1.08) | 1.01 (0.92, 1.12) | 1.01 (0.91, 1.12) | 1.00 (0.89, 1.12) | 1.00 (0.97, 1.03) |
| **Proximity to freshwater (500m)** | 0.98 (0.92, 1.04) | 0.97 (0.91, 1.04) | 0.97 (0.91, 1.04) | 0.94 (0.88, 1.01) | 0.99 (0.97, 1.00) |

* significant at $p<0.05$,

** significant at $p<0.01$;

*** significant at $p<0.001$;

[a] Odds ratios are per one interquartile range increase in NDVI;

[b] Adjusted for mother's age, prenatal visits, tobacco use, parity, education, race, insurance, and marital status;

[c] Adjusted for variables in[b] plus NSES z-score;

[d] Adjusted for variables in[c] plus town of residence

[e] Adjusted for variables in[d] plus (except when variable is the exposure of interest) NDVI (500 m buffer), residential proximity within 500 meters of a recreational facility, residential proximity within 1,000 meters of the coast, residential proximity within 500 meters of a freshwater body, and residential proximity to roadways (within 150 m of an A2 roadway or within 50 m of an A1 roadway).

## Table 3

Association between markers of green and blue space and birthweight in grams (95% confidence intervals) and between green and blue space and relative odds of small for gestational age (95% CI) among 56,633 term births in Rhode Island.

| | Unadjusted | + adjustment for patient demographics and markers of individual SES[b] | + adjustment for markers of neighborhood SES[c] | +adjustment for town of residence[d] | + adjustment for all other available environmental variables[e] |
|---|---|---|---|---|---|
| ***Birthweight (g)*** | | | | | |
| **NDVI (500 m buffer)** | 57.8 (51.7, 63.9) *** | 7.4 (0.4, 14.4) * | 7.7 (−0.5, 15.9) | −9.4 (−21.7, 2.9) | −9.1 (−21.6 3.5) |
| **Proximity to recreational facilities (500 m)** | −39.3 (−47.2, −31.4) *** | −3.4 (−11.1, 4.3) | −0.1 (−8.6, 8.3) | 2.0 (−6.6, 10.6) | −0.1 (−2.2, 2.0) |
| **Proximity to coast (1000m)** | 23.4 (14.0, 32.8) *** | 0.3 (−8.5, 9.0) | 1.2 (−7.7, 10.1) | 2.3 (−8.8, 13.4) | 0.6 (−2.0, 3.3) |
| **Proximity to coast (500m)** | 28.4 (15.7, 41.1) *** | −3.5 (−15.3, 8.3) | −3.2 (−15.1, 8.7) | −6.2 (−19.8, 7.4) | −1.5 (−4.8, 1.8) |
| **Proximity to freshwater (500m)** | 5.4 (−2.8, 13.7) | 12.1 (4.5, 19.7) ** | 11.7 (4.1, 19.4) ** | 10.2 (2.1, 18.3) * | 10.1 (2.0, 18.2) * |
| ***Small for Gestational Age*** | | | | | |
| **NDVI (500 m buffer)**[a] | 0.73 (0.69, 0.76) *** | 0.92 (0.87, 0.98) * | 0.96 (0.89, 1.03) | 1.01 (0.91, 1.13) | 1.02 (0.91, 1.13) |
| **Proximity to recreational facilities (500 m)** | 1.27 (1.19, 1.35) *** | 1.05 (0.98, 1.13) | 1.03 (0.96, 1.11) | 1.02 (0.94, 1.10) | 1.02 (0.95, 1.11) |
| **Proximity to coast (1000m)** | 0.88 (0.82, 0.95) ** | 0.96 (0.89, 1.04) | 0.97 (0.89, 1.04) | 0.95 (0.87, 1.05) | 0.95 (0.86, 1.05) |
| **Proximity to coast (500m)** | 0.91 (0.82, 1.01) | 1.03 (0.93, 1.15) | 1.05 (0.95, 1.17) | 1.10 (0.97, 1.24) | 1.10 (0.97, 1.24) |
| **Proximity to freshwater (500m)** | 0.99 (0.93, 1.05) | 0.98 (0.91, 1.04) | 0.97 (0.91, 1.03) | 0.99 (0.93, 1.06) | 0.99 (0.92, 1.06) |

* significant at p<0.05,

** significant at p<0.01,

*** significant at p<0.001;

[a] Odds ratios are per one interquartile range increase in NDVI;

[b] Adjusted for mother's age, prenatal visits, tobacco use, parity, education, race, insurance, marital status, and gestational age;

[c] Adjusted for variables in[b] plus NSES z-score;

[d] Adjusted for variables in[c] plus town of residence;

[e] Adjusted for variables in[d] plus (except when variable is the exposure of interest) NDVI (500 m buffer), residential proximity within 500 meters of a recreational facility, residential proximity within 1,000 meters of the coast, residential proximity within 500 meters of a freshwater body, and residential proximity to roadways (within 150 m of an A2 roadway or within 50 m of an A1 roadway)

## Table 4

Stratified associations between NDVI and proximity to freshwater and odds of preterm birth (95% CI) among all births (n=61,640), and between NDVI and freshwater proximity, relative odds of small for gestational age (95% CI), and mean difference in birthweight (95% CI) among term births (n=56,633)[a]

| | NDVI (500 m.) | | | Proximity to freshwater (500 m.) | | |
|---|---|---|---|---|---|---|
| | OR (95% CI) for Preterm Birth | Difference in birthweight (95% CI) | OR (95% CI) for SGA | OR (95% CI) for Preterm Birth | Difference in birthweight (95% CI) | OR (95% CI for SGA) |
| **Neighborhood SES**[b] | | | | | | |
| **$P_{heterogeneity}$** | **0.12** | **0.030** | **0.30** | **0.11** | **0.15** | **0.59** |
| 1[st] tertile | 1.09 (0.93, 1.28) | −7.9 (−27.3, 11.6) | 1.04 (0.90, 1.20) | 1.04 (0.94, 1.15) | 7.1 (−5.8, 19.9) | 0.95 (0.87, 1.05) |
| 2[nd] tertile | 1.12 (1.00, 1.26) * | 2.1 (−11.3, 15.4) | 0.95 (0.85, 1.06) | 0.98 (0.88, 1.10) | 8.7 (−4.4, 21.8) | 1.01 (0.91, 1.13) |
| 3[rd] tertile | 1.08 (0.97, 1.20) | 12.8 (0.5, 25.0) * | 0.96 (0.86, 1.07) | 0.88 (0.78, 0.99) * | 22.0 (8.4, 35.5) ** | 0.95 (0.84, 1.07) |
| **Maternal race** | | | | | | |
| **$P_{heterogeneity}$** | **0.18** | **<10ˆ−4** | **<10ˆ−5** | **0.79** | **0.13** | **0.39** |
| White | 1.05 (0.98, 1.12) | 12.1 (3.9, 20.4) ** | 0.88 (0.82, 0.94) *** | 0.98 (0.90, 1.06) | 18.0 (8.1, 27.8) *** | 0.94 (0.86, 1.02) |
| Other | 1.12 (0.98, 1.27) | −12.8 (−28.3, 2.6) | 1.11 (0.99, 1.24) | 0.96 (0.86, 1.07) | 5.0 (−8.3, 18.3) | 1.00 (0.91, 1.10) |
| **Maternal education**[c] | | | | | | |
| **$P_{heterogeneity}$** | **0.057** | **0.77** | **0.63** | **0.18** | **0.45** | **0.72** |
| Less than college | 1.15 (1.04, 1.27) ** | 10.4 (−2.3, 23.0) | 0.92 (0.83, 1.01) | 1.01 (0.92, 1.12) | 10.6 (−1.5, 22.7) | 0.98 (0.90, 1.08) |
| Any college | 1.05 (0.97, 1.13) | 4.0 (−4.5, 12.6) | 0.96 (0.89, 1.03) | 0.93 (0.85, 1.02) | 14.4 (4.4, 24.4) ** | 0.97 (0.89, 1.06) |
| **Population density**[d] | | | | | | |
| **$P_{heterogeneity}$** | **0.10** | **0.95** | **0.17** | **0.17** | **0.95** | **0.16** |
| Rural | 1.02 (0.89, 1.18) | 3.9 (−13.2, 21.0) | 0.99 (0.85, 1.14) | 0.87 (0.75, 1.01) | 11.0 (−5.7, 27.8) | 1.03 (0.88, 1.19) |
| Urban | 1.12 (1.03, 1.21) ** | 6.2 (−3.8, 16.1) | 0.93 (0.86, 1.01) | 0.99 (0.93, 1.07) | 12.2 (3.7, 20.7) ** | 0.96 (0.90, 1.03) |
| **Season of birth** | | | | | | |
| **$P_{heterogeneity}$** | **0.18** | **0.94** | **0.29** | **0.18** | **0.48** | **0.63** |
| Winter | 1.17 (1.04, 1.32) ** | 13.7 (−0.3, 28.0) | 0.97 (0.86, 1.09) | 1.09 (0.96, 1.23) | 12.2 (−3.1, 27.4) | 0.96 (0.84, 1.08) |
| Spring Summer | 1.09 (0.97, 1.21) | 7.0 (−6.3, 20.3) | 0.99 (0.89, 1.11) | 0.94 (0.83, 1.06) | 6.1 (−8.4, 20.6) | 1.01 (0.90, 1.14) |
| Fall | 1.02 (0.91, 1.16) | 3.7 (−10.2, 17.6) | 0.85 (0.76, 0.96) ** | 0.94 (0.83, 1.07) | 9.4 (−5.7, 24.4) | 1.01 (0.90, 1.14) |

| | NDVI (500 m.) | | | Proximity to freshwater (500 m.) | | |
|---|---|---|---|---|---|---|
| | OR (95% CI) for Preterm Birth | Difference in birthweight (95% CI) | OR (95% CI) for SGA | OR (95% CI) for Preterm Birth | Difference in birthweight (95% CI) | OR (95% CI for SGA) |
| | 1.08 (0.96, 1.23) | 4.5 (−10.2, 19.1) | 0.91 (0.81, 1.03) | 0.92 (0.80, 1.06) | 22.4 (6.5, 38.3) ** | 0.92 (0.81, 1.04) |

[*] significant at $p<0.05$,

[**] significant at $p<0.01$,

[***] significant at $p<0.001$;

[a] Adjusted for mother's age, prenatal visits, tobacco use, parity, education, race, insurance, and marital status. Models for birthweight are additionally adjusted for gestational age at delivery;

[b] Tertiles of NSES z-score;

[c] Less than college' includes some high school, high school complete; 'any college' includes some college, college complete, and any graduate school;

[d] Urban defined as areas with a population density of ≥1,000 persons per square mile, rural <1,000 persons per square mile.