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Disparities in Exposure to Surrounding Greenness Related to Proportion of the Population that were Immigrants to the United States

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Abstract

The proportion of the United States (US) population who are immigrants (*i.e.*, foreign-born) has been rising. Compared to the US-born, immigrants have different health risks, and prior studies could not fully explain these differences by diet and socioeconomic status. Surrounding greenness, an environmental exposure linked to better health, potentially contributes to differences in health risks between immigrants and the US-born. Using satellite imagery, we assessed exposure to surrounding greenness, as estimated by the normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI), in US Census tracts in 2000 and 2010. We then investigated the association between the percentage of the population that were immigrants and greenness using spatial error regression. Adjusted for median household income, urbanicity, educational attainment, unemployment, elderly and youth population proportion, and ecozone, a ~10% higher overall immigrant percentage points was, on average, ~0.06 NDVI/EVI interquartile range lower, indicating lower greenness. The pattern of negative associations was most consistent when the immigrant country of origin was in Latin America. Conversely, when the immigrant country of origin was in Europe, we found mostly positive associations. Our findings suggest an environmental exposure disparity by immigrant status, motivating future work on environmental contributions to health disparities between immigrants and the US-born.

Graphical Abstract

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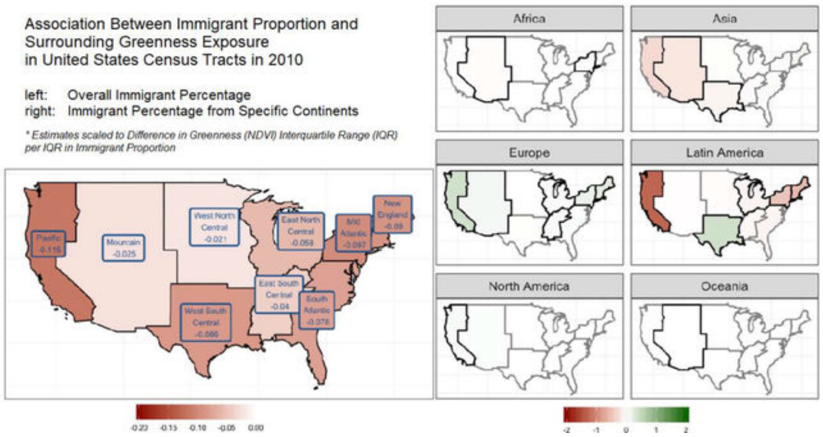
This study did not involve experimentation of human or animal subjects.

Conflict of Interest
The authors declare no conflicts of financial or personal interest that could inappropriately influence this work.



Keywords

Surrounding Greenness; Green Space; Immigrant Health; Spatial Regression; Environmental Disparity; Normalized Difference Vegetation Index

Introduction

The number of immigrants (*i.e.*, foreign-born) living in the United States (US) has steadily risen since the Immigration and Nationality Act of 1965 abolished quotas based on national origin (H.R. 2580, 1965). In 1970, 4.7% of the US population was foreign-born; today, the percentage of the US population that are immigrants is around 14% (Passel and Cohn, 2008; Vespa et al., 2018). This immigrant population currently includes 44 million people in total, and this number is expected to rise to 69 million by 2060 (Vespa et al., 2018). By 2030, immigration will contribute more to US population growth than births (U.S. Census Bureau, 2018). Immigrants to the US experience different health risks than those born in the US (Dupre et al., 2012; Mehta et al., 2016). While socioeconomic status and cultural behaviors contribute to these variations, some studies showed that the differences in health risks could not be fully attributed to differences in educational attainment, income, or sociocultural support from living in immigrant neighborhoods (Elo et al., 2011; Riosmena et al., 2013). The full causes of these differences in health risks thus remain unknown. For the general population, the environment plays an important role in determining health risks (Global Burden of Disease Risk Factor Collaborators, 2018); however, their possible role in contributing to health differences between immigrants and those born in the US is understudied (Eamranond and Hu, 2008).

Surrounding greenness is increasingly recognized as an important environmental determinant of health (for reviews see Fong et al., 2018a; James et al., 2015; Markevych et al., 2017), with most studies finding positive associations between higher levels of greenness and health. Surrounding greenness is typically measured by satellite remote sensing, which leverages chlorophyll's property of absorbing red visible light to calculate an index based on intensities of reflected infrared and visible red light (Weier and Herring, 2011). This index is representative of the amount of photosynthetic vegetation, or greenness, in an area on earth. The most commonly used greenness index is the normalized vegetation difference index

(NDVI) at 250 m^2 spatial resolution. Higher resolution (*i.e.*, 30 m^2) NDVI and the enhanced vegetation index (EVI), which corrects for solar incident angle, canopy effects, background and atmospheric noise, also exist but are sparsely used in health research (Huete et al., 2002). Exposure to greenness measured by NDVI has been linked to reduced risk for chronic diseases such as cardiovascular disease and obesity (Brown et al., 2016) as well as improvement in mental health (Banay et al., 2019). The proposed pathways through which greenness improves health includes reducing harm from environmental stresses such as heat and air pollution, restoring mental and physical capacities, and facilitating physical activity and social cohesion (Markevych et al., 2017). Thus, we investigated the relationship between area-level (*i.e.*, Census tract level) immigrant proportion and surrounding greenness, since variations in greenness exposures could partially explain health disparities between immigrants and the US-born. Our analysis estimated the associations between overall immigrant percentage or immigrant percentage from specific continents of origin and greenness in US Census tracts in 2000 and 2010.

Methods

Immigrant Proportion

Data on the proportion of the general population who were immigrants (*i.e.*, foreign born) to the US were retrieved from the US Census Bureau at the Census tract level for the years 2000 and 2010 (U.S. Census Bureau, 2019). Specifically, this proportion of the general population represents those who were born outside the US and were counted by the US Census Bureau as residing in a given Census tract in 2000 or 2010. The 2000 data were mapped onto the 2010 U.S. Census tracts using the Longitudinal Tract Database to maintain geographic boundary consistency since Census tract boundaries changed between 2000 and 2010. We also retrieved data on the proportion of immigrants from specific continents and continental sub-regions of origin. These included Africa, Asia, Europe, Latin America, North America, and Oceania (see Table S1 for countries' classification in Supplement). These proportions were recorded as percentages of the total population that were first-generation immigrants in individual Census tracts.

Normalized Difference Vegetation Index (NDVI)

Surrounding greenness was assessed through the normalized difference vegetation index (NDVI), which is derived from satellite imagery (Weier and Herring, 2011). NDVI is the ratio of the difference between an area's reflected near-infrared light and visible red light divided by the sum of the two. It ranges from −1 to +1, with higher values indicating higher levels of vegetation.

We retrieved annually-averaged NDVI from Google Earth Engine for the years 2000 and 2010 (Gorelick et al., 2017). These satellite remote sensing products have a spatial resolution of 250 m^2 and were measured by the moderate-resolution imaging spectroradiomenter (MODIS) aboard the Terra satellite of the National Aeronautics Space Administration (NASA, 2019). With these satellite images, we calculated area-weighted annual average NDVI at the Census tract level in R using the 'sf' package (Pebesma, 2018; R Core Team, 2019). As sensitivity analyses, we also considered the enhanced vegetation index (EVI) at 250 m^2 resolution and NDVI at 30 m^2 resolution from Landsat. Furthermore, we address the possibility of bias from unequal distribution of water bodies among Census tracts by multiplying the Census tract average NDVI by a correction factor based on that Census tract's land area divided by the total area including water area. In total, 70,392 Census tracts in 2000 and 68,312 in 2010 were successfully linked to greenness data (Table 1).

Statistical Analysis

Our primary goal was to estimate the association between immigrant proportion and greenness at the Census tract level. A secondary goal was to assess if the association differed by immigrants' continent or continental sub-region of origin. We performed separate analyses for years 2000 and 2010, and also on the association between change in immigrant proportion and change in greenness from 2000 to 2010.

We used spatial error regression to estimate the association between immigrant percentage and NDVI. As the name suggests, spatial error regression does not assume independent errors but rather allows errors to be distributed by a spatial autoregressive process (Bivand and Piras, 2015; Casey et al., 2017).

$$NDVI_i = \beta_0 + \beta_1 ImmP_i + \beta_{2..n} X_{2..n,\,i} + \varepsilon_i \quad (1)$$

Equation 1 shows the equation for the spatial error regression with $ImmP$ representing immigrant percentage and X representing the set of explanatory variables in Census tract i. It resembles a linear regression except that the error term ε of neighboring Census tracts can be correlated. This is to account for possible spatial correlation in greenness, measured by NDVI, in neighboring Census tracts. As climate varies by geographic region, we ran separate regressions for each of the nine regions defined by the US Census (see Table S2 for states classification in Supplement). In each regression, we estimated the association between immigrant percentage and NDVI, adjusted for corresponding year's median household income, urbanicity, educational attainment, unemployment, elderly population proportion, and youth population proportion (U.S. Census Bureau, 2019). Median household income was included as a four-category variable with the 25^{th}, 50^{th}, and 75^{th} percentile in annual household income in the US during the study years as cut points. In 2000, these cut points were $27,500, $52,500, and $82,500; in 2010, they were $30,000, $60,000, and $100,000. Urbanicity was considered as dichotomous as classified by the U.S. Census Bureau; both urban areas and urban clusters were considered urban in our analysis (U.S. Census Bureau, 2012). Educational attainment, unemployment, elderly population proportion and youth population proportion were each four-category variables with empirical 25^{th}, 50^{th}, and 75^{th} percentiles of each variable in each study year as cut points. For educational attainment, the percent of the Census tract college-educated or higher was used; for unemployment, the percent unemployed; for elderly population proportion, the percent ≥65 years of age; for youth population proportion, the percent <18 years of age. To account for potential greenness differences due to climate, we also included a categorical variable for Omernik level II ecozone (Omernik, 1987; Omernik and Griffith, 2014). In these regressions, the relationship between the explanatory variables and the outcome was assumed to be additive and linear; we tested this assumption by testing if a non-linear natural spline for immigrant proportion improved model fit.

In a separate set of regressions, we estimated the association between immigration percentage from each continent or continental sub-region of origin and NDVI. We scaled our estimates per interquartile range (*i.e.*, 25^{th} to 75^{th} percentile; IQR) in immigrant percentage from that continent or continental sub-region of origin. Since there was variability in greenness between Census regions, we also scaled the estimated effects to each region's NDVI IQR. As sensitivity analyses, we repeated our main model with short-term (summer average) and long-term (2-year and 5-year average) greenness, and also stratified analyses with either only urban Census tracts or rural Census tracts. All statistical analyses were conducted in R (R Core Team, 2019), implementing the 'spdep' package (Bivand and Piras, 2015). Statistical significance was assessed at the alpha = 0.05 level.

Results

Summary statistics of Census tracts are given in Table 1. Average greenness, as measured by multiple indices including NDVI and EVI, did not change considerably from 2000 to 2010 (Table S4 in Supplement). However, overall immigrant percentages increased from 2000 to 2010. Except for immigrant percentage from North America and Europe, immigrant percentages from specific continents were higher in 2010 than in 2000. The overall immigrant percentage IQR across all Census tracts was 11.29% in 2000 and 14.78% in 2010. We mapped mean immigrant proportion and greenness in both years in Figure S1 and summarized other categorical variables included in analyses in Table S3 (Supplement). Census tract immigrant percentage was highest in the Pacific Census region followed by Mid-Atlantic and lowest in East South Central followed by West South Central. Census tract mean greenness was highest in East South Central followed by South Atlantic and lowest in Mountain followed by Pacific. Furthermore, in both years, urban Census tracts had significantly lower greenness (NDVI at 250 m^2) compared to rural Census tracts in all Census regions except the Mountain region; Census tracts with higher median household income had higher greenness compared to those with lower median household income in most Census regions. Moreover, Census tracts with higher employment were lower in greenness while Census tracts with higher youth or elderly proportion had higher greenness.

Overall Proportion of Immigrants and Greenness Exposure

Nationally, Census tracts with higher overall immigrant percentage had significantly lower greenness (Table 2). For 2000 and 2010, Census tracts were, on average, about 0.06 IQR in NDVI (at 250 m^2) lower per IQR increment in immigrant proportion. From sensitivity analyses using other indices of greenness (EVI at 250 m^2, NDVI at 30 m^2, and NDVI at 250 m^2 with water body correction), we had similar results with slightly more negative associations when using NDVI at 30 m^2 and NDVI at 250 m^2 with water body correction.

In all 9 Census regions for both years (2000 and 2010), higher overall immigrant percentage in a Census tract was associated with lower greenness (Figure 1). For 2000, Census region-specific estimates ranged from −0.008 (95% confidence interval (CI): −0.018, 0.002) to −0.143 (95% CI: −0.164, −0.121) difference in NDVI IQR per IQR in immigrant percentage points (Figure 1A). In other words, in each Census region except West North Central, we found that higher immigrant proportion had significantly lower greenness exposures, adjusted for median household income, urbanicity, educational attainment, unemployment, elderly population proportion, youth population proportion, and Omernik ecozone. The largest significant negative association occurred in Pacific, followed by the New England Census region; the smallest significant negative associations were in the Mountain and East South Central Census regions. There was no clear east-west or north-south trends, although the largest negative associations occurred in coastal regions (Pacific and New England). We show the differences in NDVI per 1% higher immigrant percentage point in Table S5 (Supplement).

In 2010, we also found associations between higher immigrant percentage and lower greenness for each Census region, ranging from −0.021 (95% CI: −0.033, −0.010) to −0.115 (95% CI: −0.133, −0.096) difference in NDVI IQR per IQR in immigrant percentage points (Figure 1B). Contrasting results from 2000, all negative associations from 2010 were statistically significant. The largest negative association occurred again in the Pacific, followed by the Mid-Atlantic region; the smallest negative association occurred in West North Central followed by Mountain region. Again, there were no clear east-west or north-south trends. The ranking of magnitude of associations remained mostly unchanged between years 2000 and 2010. Sensitivity analyses using other greenness indices led to similar results in the associations between immigrant proportion and greenness (Figure S2 in Supplement). We also investigated immigrant proportion's association with short-term (summer average) and long-term (2-year and 5-year average) exposures to greenness and found similar patterns of associations (Figure S3 in Supplement).

We tested for nonlinearity and found that a nonlinear natural spline term with 3 degrees of freedom for immigrant proportion did not significantly improve model fit in either 2000 ($p = 0.15$) or 2010 ($p = 0.25$). We also conducted stratified analyses by urbanicity and found that increased immigrant percentage was still negatively associated with average NDVI, except for the Mountain region in 2000 with urban Census tracts, and for two Census regions with rural Census tracts in 2000 and three in 2010 (Table S6 in Supplement). Lastly, we investigated the association between change in immigrant proportion and change in average greenness (Figure S4A in Supplement). We found significant associations in three of the nine Census regions, with increased immigrant proportion in West North Central, East South Central, and Mid-Atlantic associated with decreased Census tract average Greenness from 2000 to 2010. In other Census regions, estimates were close to null.

Immigrant Proportion from Specific Continents and Greenness Exposure

Figure 2 shows the associations between Census tract immigrant proportions from specific continents or continental sub-regions of origin and greenness as measured by NDVI in 2000 and 2010. For 2000, higher Census tract immigrant percentages from Latin America were significantly associated with lower greenness in all but two Census regions (Figure 2A; Table S5A in Supplement). The pattern of associations across Census regions was similar to the results with overall immigrant percentage (Figure 1A). For immigrant percentages from Africa or Asia as the continent of origin, we found significant negative associations in two

Census regions. Overall, point estimates in all Census regions were closer to the null compared to results pertaining to immigrant percentages from Latin America. Conversely, for 2000, higher Census tract immigrant percentages from Europe were significantly associated with higher greenness in all but two Census regions. To a lesser degree, in three Census regions, higher Census tract immigrant percentages from North America were significantly associated with higher greenness. The associations for when the continent of origin was Oceania were positive but not statistically significant. When the immigrant percentage continent of origin was Africa or Asia, associations with greenness in some Census regions were positive but not statistically significant.

Results based on immigrant percentage from specific continents or continental sub-regions of origin for 2010 were similar to those for 2000 but mostly weaker in statistical significance and magnitude (Figure 2B; Table S5B in Supplement). The association between Census tract immigrant percentage and greenness was significantly negative when the continent/sub-region of origin was Latin America in four Census regions. In West South Central, the association between immigrant percentage from Latin America and greenness was significantly positive. Similar to 2000, for immigrant percentage from Asia, the associations with greenness were significantly negative in the same two Census regions (West South Central and Mountain). Unlike 2000, for immigrant percentage from Africa, there was one significant negative association in one Census region (Mountain) and one significant positive association in another (Mid-Atlantic). The association between immigrant percentage from Europe and greenness was significantly positive in all but three Census regions. Overall, estimates for 2010 were closer to the null and more varied in terms of direction compared to estimates for 2000. Across all Census regions, irrespective of continent of origin, there was no clear east-west or north-south geographical trends in associations for either 2000 or 2010; however, most significant associations occurred in Census regions closer to the coasts.

We found similar patterns of associations using other greenness indices (Figure S5 in Supplement). In both years, most significant negative associations occurred when the immigrants' country of origin was in Latin America. In 2010, we found again in the West South Central region a significant positive association between immigrant proportion from Latin America and greenness using EVI at 250 m^2 and NDVI at 30 m^2 but not with NDVI at 250 m^2 with water body correction. When the immigrants' country of origin was in Europe, we found significant positive associations in most Census regions regardless of greenness index. With other continents/sub-regions of origin, there were more differences depending on choice of greenness index. When NDVI at 30 m^2 was used, immigrant percentage from Asia and greenness had a significant positive association in New England in 2010. When NDVI at 250 m^2 with water body correction was used, more Census regions had significant negative associations when the immigrants' country of origin was in Asia. Immigrant percentages from Oceania had few negative significant but close-to-null associations when NDVI at 30 m^2 or NDVI at 250 m^2 with water body correction was used.

Discussion

Our analysis of surrounding greenness exposures in 2000 and 2010 demonstrates an environmental exposure disparity where Census tracts with higher proportion of the general population that were immigrants experienced lower greenness exposure. This suggests that immigrants tended to live in areas with lower surrounding greenness compared to the US-born. The association between higher immigrant proportion and lower greenness exposure was most consistent across all Census regions when the immigrants' country of origin was in Latin America, while when the immigrants' country of origin was in Europe, we observed mostly associations between higher immigrant proportion and higher greenness. When the immigrants' country of origin was in Asia or Africa, the associations were more heterogeneous with weaker magnitude and statistical significance.

Lower greenness in Census tracts of higher immigrant percentage could stem from area-level socioeconomic status (SES) differences. Although we adjusted for variables related to neighborhood SES, which included Census tract median household income, educational attainment, and unemployment, we recognize that they may not constitute a fully adequate proxy for neighborhood SES (Mode et al., 2016). Further evidence that suggest a link from lower Census tract greenness to neighborhood SES were the finding of lower levels of greenness associated with the percentage of immigrants from Latin America but higher levels of greenness associated with the percentage of immigrants from Europe. In the past few decades, immigrants from Latin America had lower SES compared to those from Europe (National Academies of Sciences, 2015). Adding to this, previous studies found a positive association between higher SES and greenness, especially in urban areas (Klompmaker et al., 2018; Singer, 2004; Wen et al., 2013).

The overall finding of lower greenness associated with higher immigrant percentage also could not be explained by whether or not the Census tract was an urban area, which we adjusted for in our analysis. Additionally, our sensitivity analyses stratified by urbanicity similarly consistently found higher immigrant percentage associated with lower greenness in urban Census tracts only or rural Census tracts only (Table S6 in Supplement). Since urban areas tend to have lower greenness than rural areas, the associations for rural areas were usually larger in magnitude than those for urban areas. Our analysis also accounted for potential confounding from Census tract demographics (elderly and youth population proportions) and differences in greenness associated with Omernik level II ecozone. We found the estimated effects on greenness from the set of explanatory variables were statistically significant. Thus, our results suggest that independent of the Census tracts' median household income, urbanicity, educational attainment, unemployment, elderly population proportion, youth population proportion, and ecozone, immigrants were more likely to reside in areas with lower greenness compared to the US-born.

Our findings have important health implications because of the link between higher greenness and better health outcomes. Previous studies found that higher surrounding greenness is associated with increased rates of outdoor physical activity, decreased risk of being overweight, decreased risk of having depressive symptoms, and decreased risk of adverse birth outcomes (Banay et al., 2017; Banay et al., 2019; Fong et al., 2018a; James et al., 2015; Klompmaker et al., 2018; McEachan et al., 2016). A prior cohort study found a 1.2% lower mortality rate for a 0.01 higher NDVI exposure (James et al., 2016), which is approximately half the greenness difference between a Census tract at the 25^{th} percentile of immigrant proportion versus one at the 75^{th} percentile from our analysis. The NDVI IQR difference in our analysis has also been associated with improved birth outcomes: approximately 0.4% lower odds of being small for gestational age or low birth weight, which are both risk factors for chronic disease over the life course (Fong et al., 2018b). As immigrants often settle in areas that already have an existing immigrant community (Baird et al., 2008), we expect the negative association between immigrant percentage and greenness to persist as immigration to the US continues to grow in the 21st century (Vespa et al., 2018). From 2000 to 2010, Census tracts in our analysis experienced increases to immigrant percentage, with the largest average increases for those that were 10% to 20% immigrant in 2000 (Table S7 in Supplement). We found weak evidence to support that increases to Census tract immigrant proportion from 2000 to 2010 was associated with decreases to greenness (Figure S4A in Supplement). When this analysis was narrowed to immigrant proportion from specific continents and sub-regions, there was stronger evidence to support that Census tracts with increased immigrant percentages from Latin America experienced greenness decreases and that Census tracts with increased immigrant percentages from Europe experienced greenness increases (Figure S4B in Supplement). This pattern of associations was weaker and statistically significant in fewer Census regions for immigrants from Asia (decreased greenness) and immigrants from North America (increased greenness).

Our study had limitations, motivating future analyses. Although Census tract average NDVI at 250 m^2 derived from MODIS is commonly used to assess surrounding greenness (James et al., 2015), they sometimes misclassify the exposures that the residents of these Census tracts experience. We addressed potential exposure misclassification by choice of greenness index by performing sensitivity analyses using EVI at 250 m^2, NDVI at 30 m^2, and NDVI at 250 m^2 with water body correction. Our overall conclusions were robust regardless of the greenness index used. However, exposure misclassification could still have occurred since residents could be exposed to different levels of greenness due to commuting to a Census tract with a different amount of greenness for employment. In addition, greenness indices derived from satellite imagery such as NDVI and EVI may not capture the different pathways through which greenness is theorized to benefit health (Markevych et al., 2017); it is possible that these indices do not accurately distinguish between different types of green space, or access to recreational areas, which promote physical activity and social cohesion. Future analyses can incorporate a measure of greenness that is not derived from satellite imagery. However, such a measure of greenness with high temporal and spatial coverage does not exist and would be difficult to compile. In our analysis, while we generated national and Census regional estimates adjusted for Omernik ecozones, and while the direction of these results was consistent across Census regions, geographic designations (*i.e.*, Census region) could obscure heterogeneity in the relationship between Census tract immigrant proportion and greenness. Future research is needed to assess how much heterogeneity exists. Another limitation of the current study is generalizability. The current study was based on first-generation immigrant (*i.e.*, foreign-born) proportion and greenness in Census tracts. Although we had narrowed the focus to immigrant proportion from specific continents and sub-regions, there is great diversity among immigrants and more factors to explore further. For example, future work may investigate if time since immigration contributes to greenness and other environmental exposure disparities. A deeper investigation into the persistence of environmental exposure disparities may look at the relationship between second-generation immigrant (*i.e.*, children of immigrants) proportion and greenness. Lastly, to gain a more complete understanding of how immigrants may experience different health risks compared to the US-born from disparities in greenness exposure, we aim to conduct individual-level analyses in future work.

Conclusions

To our knowledge, this is the first study to investigate surrounding greenness, an environmental exposure of increasing public health relevance, in relation to immigrant proportion in the US. We found that Census tracts with higher immigrant percentage were had lower surrounding greenness in 2000 and 2010 across all Census regions, and that the pattern of negative associations was most apparent when the immigrant country of origin was in Latin America. This suggests that these areas of higher immigrant percentage have lower access to green space, and thus fewer opportunities for recreation, physical activity, and social cohesion – leading to worse health outcomes. Our findings motivate future studies on environmental health disparities among immigrants and epidemiologic analysis quantifying the mediating effect of surrounding greenness in relation to immigrant health disparities. These results would inform policymakers on where to prioritize greening initiatives to improve public health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

US	United States
NDVI	Normalized Difference Vegetation Index
EVI	Enhanced Vegetation Index
IQR	Interquartile Range

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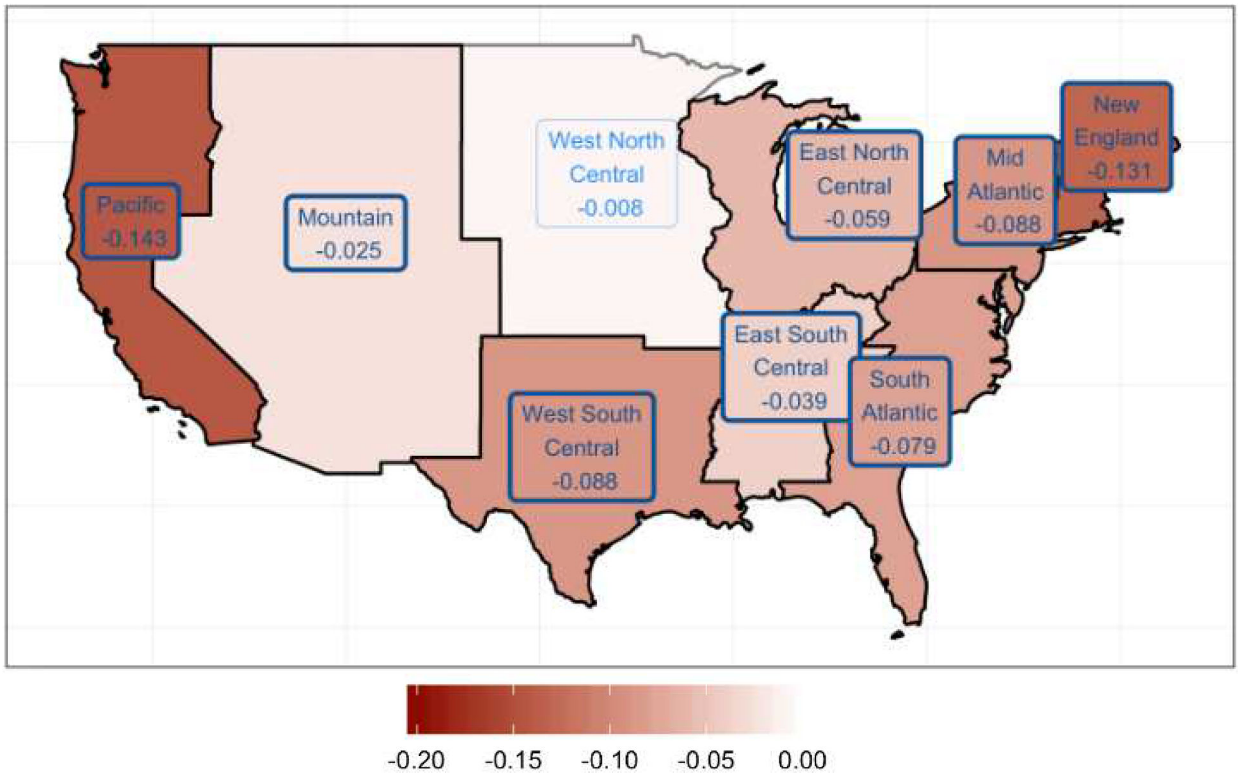
Highlights

- Surrounding greenness is an environmental exposure linked to health benefits.
- We explore the relationship between immigrant proportion and greenness.
- Areas of higher immigrant proportion experienced lower greenness in 2000 and 2010.
- The association between immigrant proportion and lower greenness was most consistent when the immigrant country of origin was in Latin America.
- Findings motivate future work on environmental contributions to immigrant health disparities.

A) Year = 2000


Pacific
-0.143
Mountain
-0.025
West North
Central
-0.008
East North
Central
-0.059
Mid
Atlantic
-0.088
New
England
-0.131
West South
Central
-0.088
East South
Central
-0.039
South
Atlantic
-0.079
-0.20 -0.15 -0.10 -0.05 0.00

B) Year = 2010

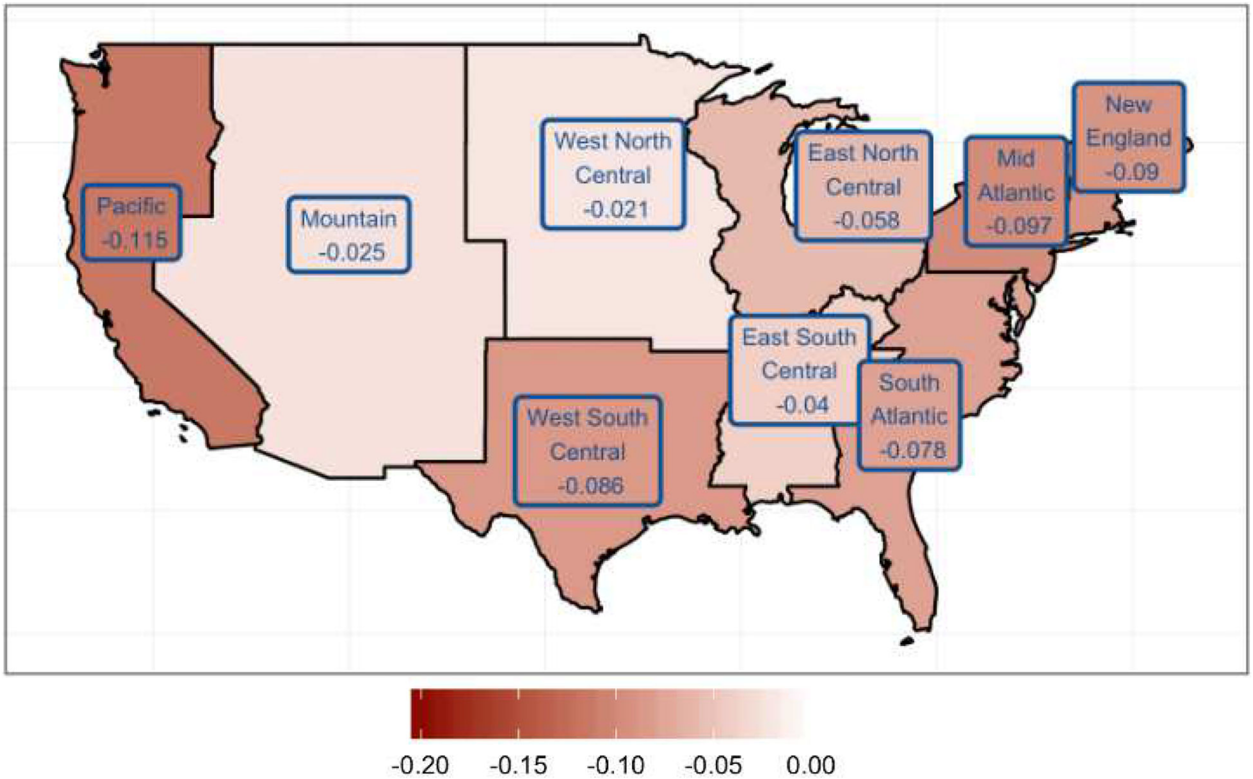
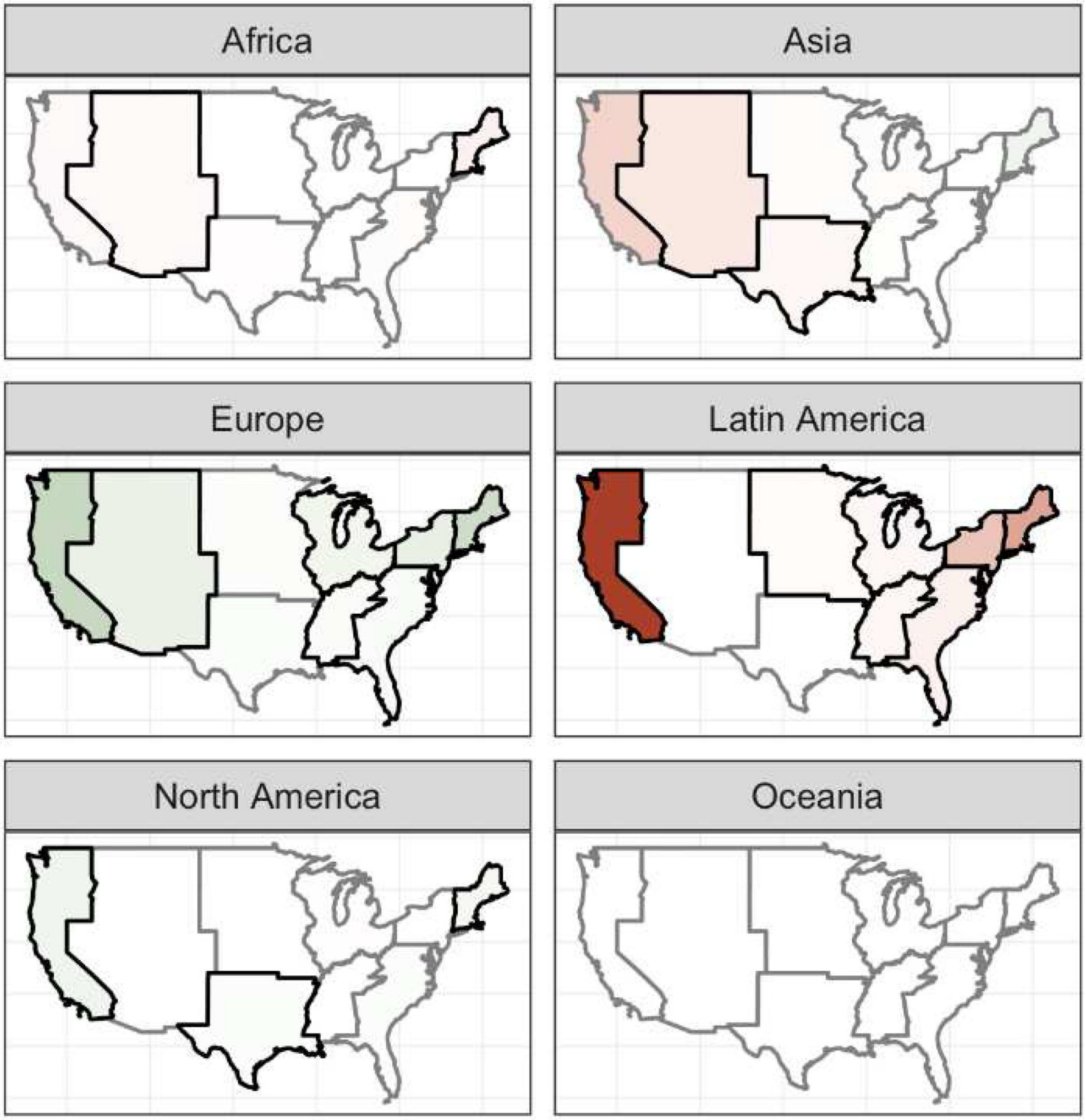


Figure 1).

Associations between Immigrant Proportion and Average Annual Greenness in US Census Tracts in 2000 (A) and 2010 (B). Separate regressions were run for each Census region. On each label, the Census region and point estimate of the associated normalized difference vegetation index (NDVI) difference, scaled to interquartile range (IQR) in NDVI in that region, per IQR in immigrant percentage are given. These estimates were adjusted for median household income, urbanicity, educational attainment, unemployment, elderly population proportion, youth population proportion, and Omernik level II ecozone. A negative estimate indicates that higher immigrant proportion was associated with lower NDVI, indicating lower greenness. Statistically significant ($p < 0.05$) associations have thick bolded borders; areas with thin borders have associations that are not statistically significant.

A) Year = 2000



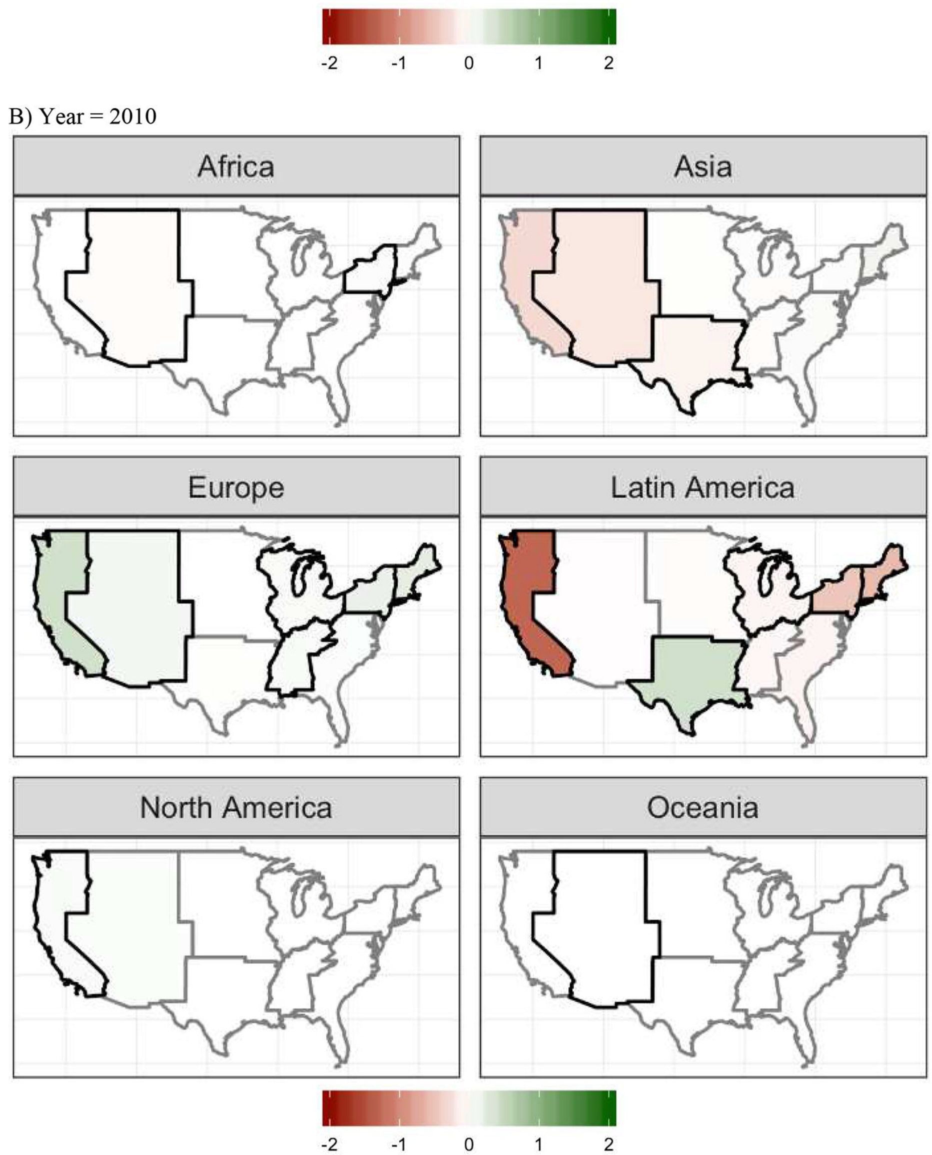


Figure 2).

Associations between Immigrant Proportion from Specific Continents or Continental Sub-Regions and Average Greenness (NDVI) in US Census Tracts in 2000 (A) and 2010 (B). Estimates represent the difference in average greenness, scaled to the interquartile range (IQR) of NDVI, per IQR difference in Census tract immigrant proportion from specific continents/sub-regions. Results were adjusted for median household income, urbanicity, educational attainment, unemployment, elderly population proportion, youth population proportion, and Omernik level II ecozone. Statistically significant associations ($p < 0.05$) have black borders.

Table 1:

Summary Statistics of Census Tracts included in Analysis. Interquartile ranges (IQR) are shown for average greenness index and immigrant proportions.

	Year	
	2000	***2010***
Number of Census Tracts	70,392	68,312
Average Greenness Index (IQR)		
NDVI at 250 m^2	0.45 (0.21)	0.43 (0.20)
EVI at 250 m^2	0.28 (0.14)	0.26 (0.12)
NDVI at 30 m^2	0.26 (0.12)	0.28 (0.13)
NDVI at 250 m^2 with Water Body Correction	0.47 (0.22)	0.45 (0.20)
Average Immigrant Proportion (%) (IQR)		
Overall	10.47 (11.29)	12.47 (14.78)
from Asia	2.71 (2.55)	3.38 (3.53)
from Africa	0.31 (0.27)	0.50 (0.36)
from Europe	1.72 (1.72)	1.63 (1.81)
from Latin America	5.38 (4.43)	6.62 (6.99)
from North America	0.30 (0.41)	0.28 (0.35)
from Oceania	0.05 (0)	0.06 (0)
Census Region (n) (% of total)		
East North Central (ENC)	11,488 (16.3)	11,002 (16.1)
East South Central (ESC)	4234 (6.0)	3753 (5.5)
Mid-Atlantic (MAT)	9731 (13.8)	9565 (14.0)
Mountain (MTN)	5174 (7.4)	5114 (7.5)
New England (NEN)	3292 (4.7)	3278 (4.8)
Pacific (PAC)	10,146 (14.4)	10,114 (14.8)
South Atlantic (SAT)	13,158 (18.7)	12,765 (18.7)
West North Central (WNC)	5203 (7.4)	5013 (7.3)
West South Central (WSC)	7966 (11.3)	7708 (11.3)
Urban Area (n) (% of total)	48,887 (69.4)	47,931 (70.2)

Table 2:

National Estimates of the Association between Census Tract Immigrant Proportion and Greenness. Greenness indices used were the normalized difference vegetation index (NDVI) at 250 m^2 spatial resolution, the enhanced vegetation index (EVI) at 250 m^2, NDVI at 30 m^2, and the NDVI at 250 m^2 corrected for differences in water body area in Census tracts. Estimates represent the difference in average greenness, scaled to the interquartile range (IQR) of the specific greenness index, per IQR difference in Census tract immigrant proportion. 95% confidence intervals are provided in parentheses.

	Year	
Greenness Index Outcome	**2000**	**2010**
NDVI at 250 m^2	−0.066 (−0.070, −0.061)	−0.063 (−0.068, −0.059)
EVI at 250 m^2	−0.064 (−0.068, −0.059)	−0.063 (−0.067, −0.058)
NDVI at 30 m^2	−0.070 (−0.075, −0.064)	−0.071 (−0.077, −0.066)
NDVI at 250 m^2 with Water Body Correction	−0.074 (−0.079, −0.070)	−0.079 (−0.084, −0.075)