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Redlines and Greenspace: The Relationship between Historical Redlining and 2010 Greenspace across the United States

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Introduction: Redlining, a racist mortgage appraisal practice of the 1930s, established and exacerbated racial residential segregation boundaries in the United States. Investment risk grades assigned >80 y ago through security maps from the Home Owners' Loan Corporation (HOLC) are associated with current sociodemographics and adverse health outcomes. We assessed whether historical HOLC investment grades are associated with 2010 greenspace, a health-promoting neighborhood resource.

Objectives: We compared 2010 normalized difference vegetation index (NDVI) across previous HOLC neighborhood grades using propensity score restriction and matching.

Methods: Security map shapefiles were downloaded from the Mapping Inequality Project. Neighborhood investment risk grades included A (best, green), B (blue), C (yellow), and D (hazardous, red, i.e., redlined). We used 2010 satellite imagery to calculate the average NDVI for each HOLC neighborhood. Our main outcomes were 2010 annual average NDVI and summer NDVI. We assigned areal-apportioned 1940 census measures to each HOLC neighborhood. We used propensity score restriction, matching, and targeted maximum likelihood estimation to limit model extrapolation, reduce confounding, and estimate the association between HOLC grade and NDVI for the following comparisons: Grades B vs. A, C vs. B, and D vs. C.

Results: Across 102 urban areas (4,141 HOLC polygons), annual average $\pm$standard deviation (SD) 2010 NDVI was 0.47 ($\pm$0.09), 0.43 ($\pm$0.09), 0.39 ($\pm$0.09), and 0.36 ($\pm$0.10) in Grades A–D, respectively. In analyses adjusted for current ecoregion and census region, 1940s census measures, and 1940s population density, annual average NDVI values in 2010 were estimated at −0.039 (95% CI: −0.045, −0.034), −0.024 (95% CI: −0.030, −0.018), and −0.026 (95% CI: −0.037, −0.015) for Grades B vs. A, C vs. B, and D vs. C, respectively, in the 1930s.

Discussion: Estimates adjusted for historical characteristics indicate that neighborhoods assigned worse HOLC grades in the 1930s are associated with reduced present-day greenspace. https://doi.org/10.1289/EHP7495

Introduction

Racial health inequities in the United States remain pervasive. Studies have identified multiple drivers of these inequities, ranging from increased psychosocial stress to differential access to health care, most, if not all of which derive from structural, environmental, or institutional racism (Bailey et al. 2017; Chadha et al. 2020; Krieger 2016; Wheeler and Bryant 2017; Williams 2018). Entrenched racial residential segregation in the United States is a unique driver of racial and ethnic health disparities given that it is associated with increased exposure to environmental hazards (Bravo et al. 2016; Morello-Frosch and Jesdale 2006) and decreased access to health-promoting resources (Bravo et al. 2016; Burris and Hacker 2017; Landrine and Corral 2009; Morello-Frosch and Lopez 2006). One resource thought to promote health and buffer stress is urban greenness or greenspace (Van Den Berg et al. 2007; Bratman et al. 2012; Kardan et al. 2015; McCracken et al. 2016; Ulrich et al. 1991; Ward Thompson et al. 2012). A lack of greenspace is associated with racial residential segregation and urban heat islands (Jesdale et al. 2013), more noise pollution (Dzhambov et al. 2018; Margaritis and Kang 2017), poorer air quality (Nowak et al. 2006), and lower income (Schwarz et al. 2015). A recent review reported that greenspace reduces the risk of low birth weight and premature mortality (Fong et al. 2018). Furthermore, prior work has determined that neighborhoods across the United States with a higher proportion of non-Hispanic Black residents and a greater concentration of poverty had lower levels of greenspace in 2001 (Casey et al. 2017). We sought to determine whether redlining, a historical policy that continues to contribute to present-day racial segregation in the United States, might also affect current levels of greenspace.

Following the Great Depression in the 1930s, the federal government created the Home Owners' Loan Corporation (HOLC) as part of the New Deal. The purpose of the HOLC was to rescue home owners defaulting on their mortgages across the United States (Hillier 2003; Jackson 1985). To support this task, the HOLC created security maps, standardized appraisal tools made for over 200 cities. Security maps assigned investment risk to entire neighborhoods based on a variety of factors, including prior home values, presence of industry, and racial demographics. Each neighborhood was shaded one of four colors, indicative of perceived investment risk: green neighborhoods (Grade A) were considered "best", blue (Grade B) "still desirable", yellow (Grade C) "definitely declining" and red (i.e., redlined; Grade D) "hazardous". We refer to these as HOLC grades. Standardized HOLC appraisal forms included input lines of "infiltration of" and "foreign-born" to describe the presence of people of color and neighborhoods housing more people of color was a modest predictor of being shaded in red or redlined (Gee 2008). Recent studies have found that HOLC lending patterns in the 1930s reinforced preexisting segregation in many places and that security maps and redlining is associated with present-day levels of racial segregation, poverty, and income inequality (Mitchell and Franco 2018). At a minimum, creation of these maps was determined by neighborhood demographic make-up, and the racist information documented in the

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appraisal forms shaped decisions about where to target community-rescuing investment.

HOLC Security Maps provide a unique tool through which to assess the legacy of segregation policies with geographic specificity; racist policies throughout U.S. history have structured the built environment and thus continue to influence local ecology in ways that contribute to racial health inequities (Schell et al. 2020). Studies have found associations between historical redlining, decreased tree canopy coverage (Hoffman et al. 2020; Locke et al. 2020; Namin et al. 2020), increased coverage of land by impervious surfaces, and worsened air pollution in urban areas across the United States (Hoffman et al. 2020). We build on this prior work by using satellite imagery to capture greenspace and propensity score restriction and matching to limit estimated associations to the area of support—specifically the subset of communities where redlined and non-redlined communities can serve as credible comparison populations for one another—and to reduce confounding bias. Similar to Jacoby et al. (2018) in their study of urban violence in Philadelphia, we adjusted for measured historical variables potentially acting as confounders using data from the 1940 U.S. Census because these variables may have influenced HOLC grade assignment and future greenspace. This methodological approach provides an assessment of the lingering current-day impacts of historical redlining (Jacoby et al. 2018). Here, we assess the association between HOLC grade and 2010 normalized difference vegetation index (NDVI), a measure of overall greenness. Findings from this study can inform both literature on health disparities and equity-generating policy meant to invest in communities of color that have suffered historical discrimination.

Methods

Study Design and Data Acquisition

We conducted a nationwide geospatial analysis by combining data sets from several publicly available sources. (See "Sample R Code" in the Supplemental Material.) We downloaded and included all security map shapefiles available from the University of Richmond's Mapping Inequality Project as of December 2019 (Nelson et al. 2019). These data spanned 239 cities (all urban areas) and included the neighborhood boundaries used by the HOLC in the 1930s, roughly equivalent in size to (but not the same as) present-day census tracts, referred hereafter as HOLC polygons. Only one security map was produced for each city. From the MODerate-resolution Imaging Spectroradiometer (MODIS) on the National Aeronautics and Space Administration's *Terra* satellite, we accessed NDVI data at a 250-m resolution based on the best pixels (e.g., those without cloud cover) from 16-d composite images beginning 1 January (winter), 7 April (spring), 12 July (summer), and 30 September (fall) of 2010 (Didan et al. 2015; Kriegler et al. 1969). HOLC polygons generally covered an area larger than $250\,m^2$ with a median HOLC polygon size of $802{,}316\,m^2$ or $0.80\,km^2$, and thus we considered this an adequate resolution. NDVI values range from -1 to 1 and represent the ratio of the difference between near-infrared light (reflected from leaves) and visible light (absorbed by chlorophyll in plants) to the sum of the two sets of light. If visible light is being absorbed, the numerator of the ratio will be larger, and, thus, NDVI will be closer to 1, whereas values closer to 0 indicate less light absorbed by plants (i.e., less greenness) and those of -1 represent water (Kriegler et al. 1969).

We acquired census tract shapefiles and sociodemographic variables from the 1940 U.S. Census from the Individual Public Use Microdata Series National Historical Geographic Information Systems database (Manson et al. 2019). Sociodemographic variables included total population; median home value; the number of non-White, Black, foreign-born White, and employed residents; number of residents with a high school diploma; total number of homes; number of homes needing major repairs; number of homes with radios; and number of people per housing unit (terms correspond to those used by the U.S. Census Bureau). Non-White, as defined by the U.S. Census Bureau, was an aggregate grouping of all racial groups not considered White, including Black residents (Hopkins and Austin 1940; U.S. Census Bureau 1940b). Count data were converted into proportions using the total population.

Theoretically, neighborhood demographics at the time of HOLC map creation influenced risk grades, are likely associated with modern neighborhood greenspace and, therefore, could function as confounding factors (Figure S1). Given that more than 70 y have passed between the time of the security map creation and our NDVI measurements, inclusion of such potential confounders is crucial to avoid overestimating the true effect of HOLC maps. We assigned 1940 census measures to each HOLC neighborhood boundary using areal apportionment because multiple census tracts often overlapped with each HOLC polygon (Nardone et al. 2020a). Briefly, we superimposed 1940s census tract maps onto HOLC maps and assigned the HOLC polygons 1940s-level metrics based on the areal proportion of the overlapping 1940s census tracts (Figure S2). In addition, we calculated the 1940 population density by dividing the 1940 total population by the HOLC polygon area.

We used 1940s census measures as opposed to 1930s measures for several reasons: Data for the 1940s has significantly broader geographic availability (<1,000 tracts in 1930 vs. >7,000 in 1940); HOLC maps were created in the second half of the 1930s, beginning in 1934 and ending in 1940; the population migrations occurring, in part, as a result of the Great Depression (i.e., the Great Migration) are better captured by the 1940 census rather than the one completed 10 y prior (Gutmann et al. 2016); prior studies on the current effects of historical redlining also adjusted for 1940s metrics over 1930s metrics for similar reasons (Jacoby et al. 2018). We did not include present-day sociodemographic measures in our analyses because HOLC grades reduced home ownership, investment, and degraded wealth-generating opportunities in redlined and yellow-lined communities, thus making present-day demographic variables potential mediators (Schisterman et al. 2009).

NDVI Extraction and Assignment of Regional Variables

In order to determine greenness levels within each HOLC polygon, we superimposed national NDVI raster images onto the HOLC shapefiles and extracted the mean NDVI value for each HOLC polygon. Cell values for each HOLC polygon were weighted based on the proportion of spatial overlap with a 1940s census tract (Figure S2) and normalized to account for the imperfect overlap of NDVI pixels with HOLC polygons.

The ecoregion and census region, as defined in 2020 by the U.S. Environmental Protection Agency (EPA) and the U.S. Census Bureau, of each HOLC polygon was determined based on the geometric location of the HOLC polygon centroid. U.S. Census regions have not changed since 1984, whereas Omernik's ecoregions, which are defined by ecosystem characteristics, were developed in 1987. Level I ecoregion shapefiles were downloaded from the U.S. EPA website (U.S. EPA 2020) and census region shapefiles from the U.S. Census Bureau website (U.S. Census Bureau 2020).

Areal Apportionment of 1940s Census Tract Data

A total of 8,102 HOLC polygons from 198 urban metropolitan areas across 38 states, which includes all U.S. HOLC-graded areas available on the University of Richmond's Mapping

Inequality website as of 1 February 2020, were eligible for inclusion in the analysis (Nelson et al. 2021). However, at the time of the 1940 census, only 60 U.S. cities had census tract boundaries assigned (U.S. Census Bureau 1940a). These 60 cities contained one-quarter of the nation's population. HOLC polygon neighborhood boundaries existed in areas outside of these 60 cities, and we therefore excluded HOLC polygons that did not overlap with any 1940 census tract boundaries ($N = 4{,}126$; 50.9% of HOLC polygons). We also excluded 28 (0.3%) HOLC polygons with a count of zero homes, and two polygons with a HOLC grade of E, leaving 3,946 (48.7%) polygons eligible for analyses (Figure S3) across 102 urban areas (Table S1). It is unclear what qualified a neighborhood to receive a grade of E, and given this, we eliminated these three polygons (0.02% of all HOLC polygons) from our analysis. We also conducted a sensitivity analysis, in which we excluded HOLC polygons with a <90% 1940s census tract overlap.

Statistical Analyses

Some 1930s HOLC polygons likely had little or no probability of being classified in a different HOLC grade than their actual classification. For example, we anticipated that many polygons that received Grade A had almost no chance of receiving Grade D. Including these polygons in a model estimating the relationship between redlining (i.e., Grade D vs. all else) and greenness would involve extrapolating beyond what the data could support (Petersen et al. 2012). We chose against comparing redlined neighborhoods to Grade A neighborhoods given that the Grade A neighborhoods had little to no probability of being redlined and that the redlined neighborhoods had little to no probability of being Grade A. Making comparisons between units whose exposure assignment is deterministic or close to deterministic relies heavily on extrapolating where there are no or little data and can result in significant bias. Therefore, to address this issue we limited our analyses to the following comparisons: *a*) Grade B vs. A; *b*) Grade C vs. B; and *c*) Grade D vs. C HOLC polygons, which we refer to hereafter as neighborhoods.

We estimated the propensity score based on 1940s census metrics (percentage non-White residents, percentage Black residents, percentage foreign-born residents, number of people per housing unit, median income, percentage of homes needing major repairs, percentage of employed residents, percentage of homes without a radio, percentage of residents who completed high school, and population density), Level I ecoregion, and census region using an ensemble of machine learning algorithms: generalized linear models, Bayesian generalized linear models, multivariate adaptive regression splines, and generalized additive model algorithms with the R package SuperLearner (van der Laan et al. 2007). We used separate models for each of the three exposure comparisons that included all 1940 census variables enumerated above to predict exposure to Grade B vs. A, Grade C vs. B, and Grade D vs. C.

We further restricted samples based on propensity score, which is the predicted probability of a HOLC polygon being a certain grade relative to another (Austin 2011; Stürmer et al. 2010). Neighborhoods with propensity scores above the 99th percentile of probabilities among the better-graded group propensity scores or below the first percentile of probabilities among the worse-graded group propensity scores were excluded from analyses (Stürmer et al. 2010). Figure 1 displays the resultant propensity score distributions across the three different comparisons (B vs. A; C vs. B, and D vs. C) as produced by SuperLearner, with the lines of Figure 1 indicating the related restriction cutoffs. Propensity score restriction led to the exclusion of 138 (9.3%) HOLC polygons in the Grade B vs. A analysis, 246 (9.2%) in the Grade C vs. B analysis, and 266 (10.0%) in the Grade D vs. C analysis. For instance, of the 4,141 HOLC polygons that overlapped with the 1940s census tracts, 439 were Grade A, 1,043 Grade B, 1,637 were Grade C, and 1,022 were Grade D. Thus, 1,482 polygons were eligible for propensity scoring, restriction, and matching in the B vs. A analysis, of which, 138 (9.3%) were excluded as a result of restriction (Figure S3).

Next, we matched the worse-graded (treatment) neighborhoods to better-graded (control) neighborhoods based on full matching with replacement (Colson et al. 2016; Ho et al. 2011). In addition to matching on the propensity score, we required matches to be within 0.2 standard deviations of the Mahalanobis distance for the variables percent of non-White residents and median home value. This produced HOLC-neighborhood matching weights for the B vs. A, C vs. B, and D vs. C comparisons for each HOLC polygon.

To estimate the association between historical HOLC grades and 2010 NDVI levels, we used TMLE using the propensity scores and weights calculated above (van der Laan 2010). Models included 2020 ecoregion and census region and all 1940 census variables: median home value; the percentage of non-White, Black, foreign-born White, and employed residents; percentage of residents with a high school diploma; percentage of homes needing major repairs; percentage of homes with radios; number of people per housing unit; and population density. All statistical analyses were conducted in R (version 1.3.1093; R Development Core Team). Packages used are listed in Table S2.

Results

This ecologic study evaluated the relationship between 1930s HOLC Security Risk map grades and annual average and summer 2010 NDVI in 102 U.S. urban metropolitan areas. Figure 2 illustrates NDVI and historical HOLC grade in all HOLC-graded neighborhoods, regardless of eventual propensity score, in three of the most populated cities of the United States and a notable spatial patterning of decreasing 2010 greenness in areas with worsening HOLC grade. Figure 3 groups all HOLC polygons by 0.10 increments of annual average NDVI and shows how, on average, greenness increases, the proportion of HOLC polygons graded A or B also increases.

The distribution of HOLC grade differed by ecoregion and census region (Table 1). Of the 4,141 HOLC unmatched polygons that had spatial overlap with 1940s census tracts and thus were eligible for propensity scoring, the majority were Grade C (39.5%), concentrated in the Eastern Temperate Forest ecoregion (72.8%) and were in the Midwest census region (38.0%). In all ecoregions and census regions, Grade A and Grade C assignments were the least and most common, respectively. Median home values and the proportion of residents who were employed or had a high school diploma in 1940 decreased from Grade A to Grade D while the percentage of homes needing major repairs increased. The proportions of Black and non-White residents in 1940, and the proportion of homes without a radio, were highest for Grade D HOLC areas. HOLC-graded polygons had moderately lower socioeconomic status (with lower percentage employed, with high school diploma, and with radio ownership), lower median home value, and a higher proportion of non-White residents as indicated by 1940 census measures. In 2010, annual average NDVI decreased as HOLC neighborhood grade worsened (Table 1). Distributions of sociodemographics among all polygons that underwent propensity scoring with SuperLearner and subsequent propensity score restriction and matching are shown in Table S3.

TMLE analyses were adjusted for a range of 1940 census variables, as well as census region and ecoregion, and suggested that HOLC grade was significantly associated with decrements in

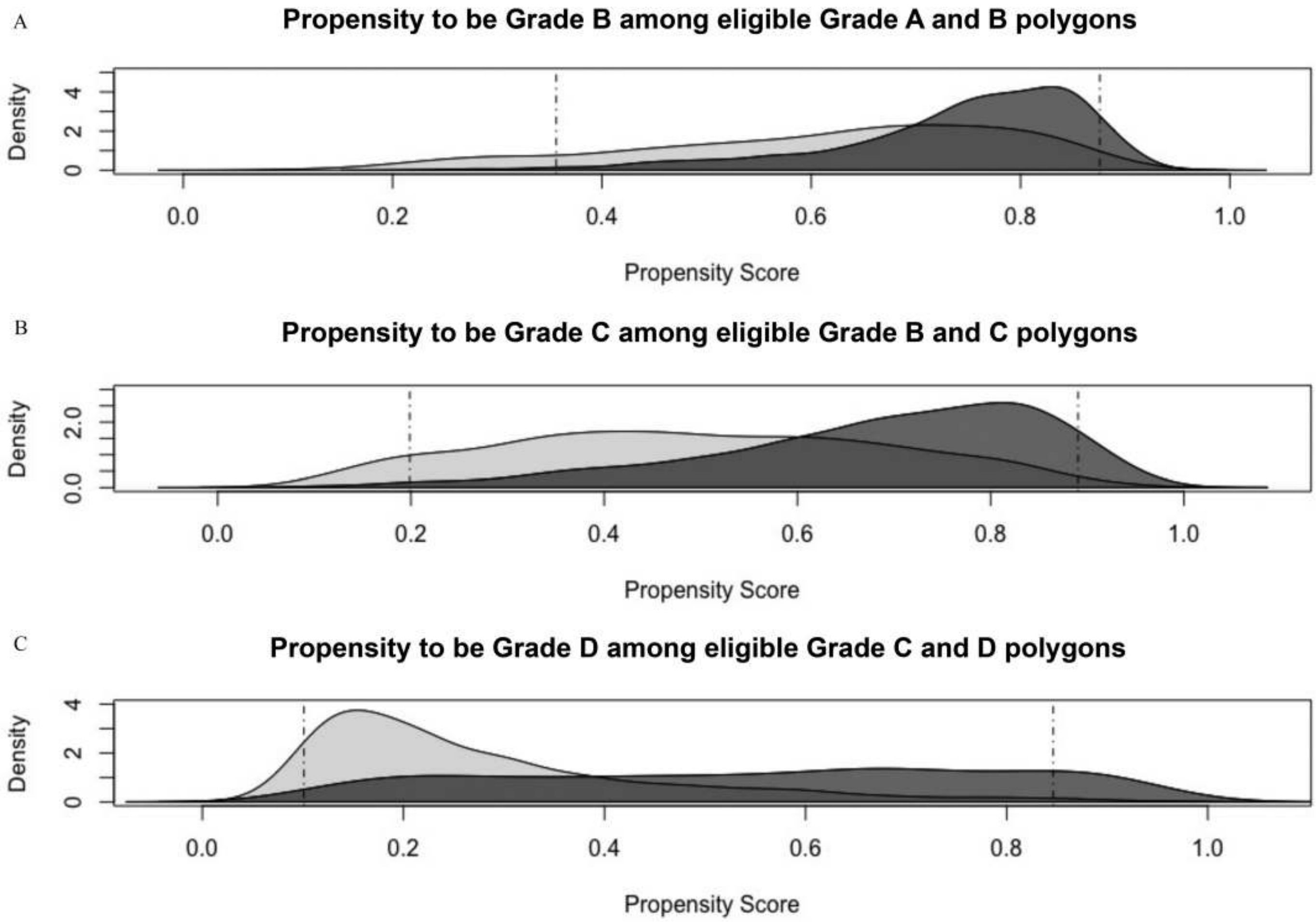

Figure 1. Nonrestricted propensity score distributions for 1940s U.S. Census tracts comparing HOLC better-graded tracts to worse-graded tracts. Propensity scores of the worse-graded group are shaded darker. (A) Propensity to be Grade B among Grades A and B HOLC neighborhoods; (B) propensity to be Grade C among Grades B and C HOLC neighborhoods; and (C) propensity to be Grade D among Grades C and D neighborhoods. Subsequent propensity score restriction cutoffs (1st and 99th percentiles) are indicated by the dashed lines. Note: HOLC, Home Owners' Loan Corporation.

annual average and summertime NDVI (Table 2). Grades B, C, and D were associated with −0.039 [95% confidence interval (CI): −0.045, −0.034], −0.024 (95% CI: −0.030, −0.018), and −0.026 (95% CI: −0.037, −0.015) lower annual average NDVI, compared with grades A, B, and C neighborhoods, respectively, as estimated by TMLE. Differences in greenspace were more drastic in summer than using the annual average. When restricting analyses to HOLC polygons that had ≥90% overlap with 1940 census tracts [$N = 3{,}747$ (90.5% total eligible polygons); $A = 387$ (88.2%), $B = 932$ (89.4%), $C = 1{,}476$ (90.2%), $D = 952$ (93.2%)], decreases in greenspace remained similar (Table S4).

Discussion

Historical redlining is one of many institutionally racist policies that contributed to the current patterns of racial residential segregation and wealth disparities in the United States (Michney and Winling 2020; Mitchell and Franco 2018). Such policies diminished access to wealth and wealth accumulation across generations (Aaronson et al. 2019), the effects of which are, in part, reflected by the racial wealth gap today (Kochhar and Fry 2014). Aside from impacting intergenerational wealth, other local, state, and federal policies in conjunction with redlining, sculpted neighborhood physical environments in ways that contribute to current health risks. In the present study, we found evidence of an association between worse historical HOLC grade and less 2010 greenspace using data from 102 U.S. urban metropolitan areas. Our analyses uniquely compared 2010 greenspace between neighborhoods with different HOLC grades but otherwise similar sociodemographic characteristics according to the 1940s census.

With similar goals of assessing how the current built environment is associated with HOLC maps, Hoffman et al. (2020) estimated an association between elevated ambient temperature, increased presence of impervious surfaces, and decreased tree canopy coverage in previously redlined areas compared with non-redlined areas. Across the 108 urban areas included in their analysis, redlined areas were on average 2.6°C warmer than their Grade A neighbors. The authors surmise this is due, in part, to highway construction through worse-graded neighborhoods and building construction using heat-retaining materials, activities that took place predominantly in redlined neighborhoods in the decades that followed the HOLC Security Map creation. This argument is supported by their finding of increased impervious land cover and decreased tree canopy coverage with worsening HOLC grade. Last, the findings of Hoffman et al. (2020) varied across cities and regions. Our analyses adjusted for both ecoregion and census region to examine overarching patterns of redlining on greenness using a propensity scoring approach given that we did not have *a priori* hypotheses regarding city or regional differences. However, future studies could apply similar methods to analyze metropolitan- and regional-specific associations and assess the extent to which state, county, or city-level policies

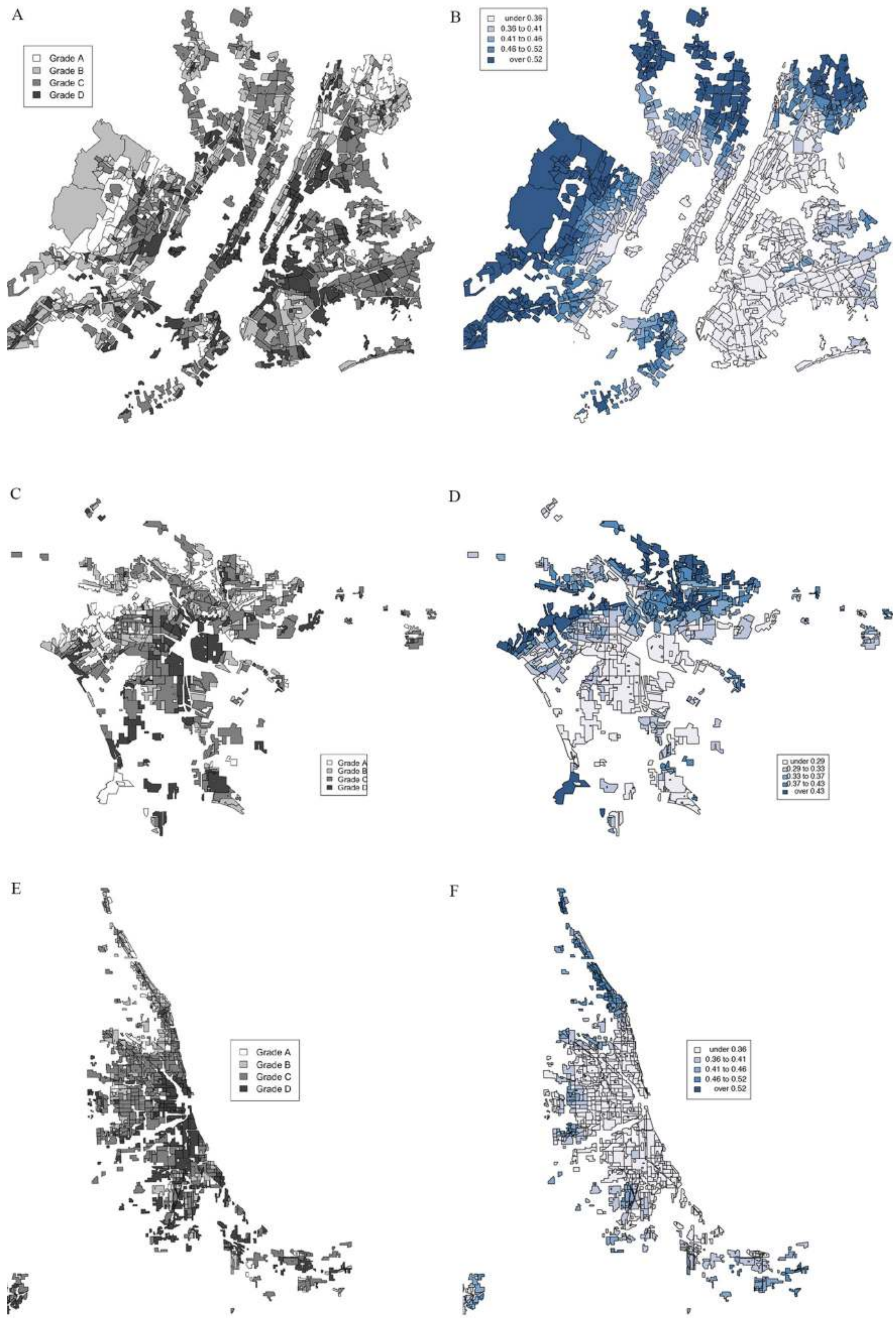

Figure 2. Ecoregion-specific normalized difference vegetation index (NDVI) quintiles in all HOLC polygons across the Chicago, Los Angeles, and New York City urban areas. Images (A, C, E) in the left column are assigned HOLC grades. Images (B, D, F) in the right column are 2010 NDVI quintiles, with the deeper shade of blue indicating higher levels of greenness. (A) and (B) corresponds to the New York City metropolitan area. (C) and (D) corresponds to the Los Angeles metropolitan area. (E) and (F) corresponds to the Chicago metropolitan area. Note: HOLC, Home Owners' Loan Corporation.

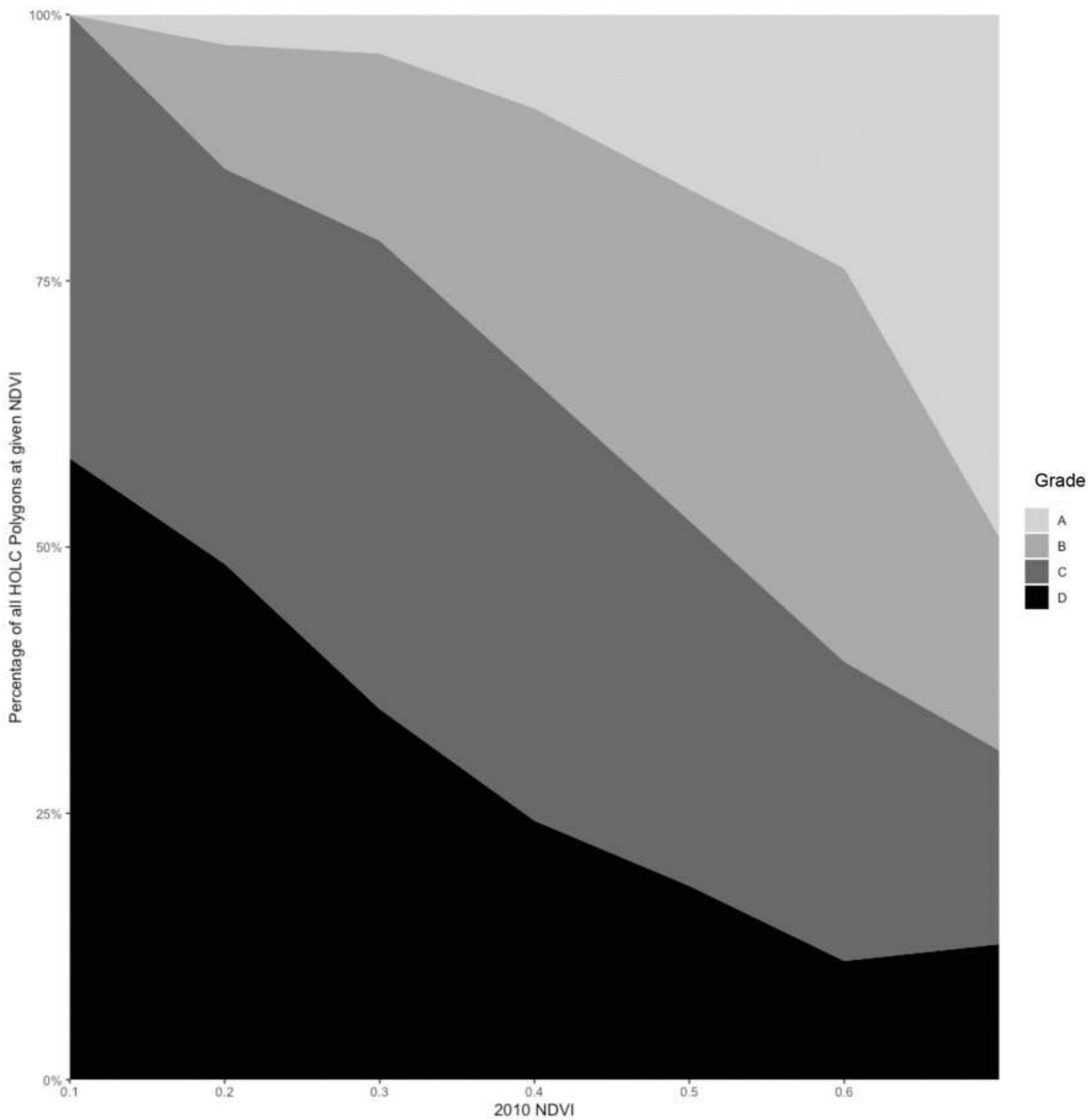

Figure 3. Percentage of all HOLC polygons at a given mean annual 2010 NDVI stratified by HOLC grade. Note: HOLC, Home Owners' Loan Corporation; NDVI, normalized difference vegetation index.

may modify observed relationships between HOLC grade and greenspace.

Other recent work by Locke et al. (2020) found evidence of an association between current tree canopy coverage and HOLC grade in 37 U.S. cities. Unlike our analyses, Locke et al. (2020) compared Grade A to Grade D and found that Grade D neighborhoods had 21% less tree canopy coverage compared with Grade A neighborhoods, with the possibility of extrapolating beyond the support of the data. This analysis selected cities for which data of high-resolution tree canopy, defined as "the layers of leaves, branches, and stems of trees that cover the ground when viewed from above," were available. Although we used a different greenspace outcome metric (i.e., the NDVI) than the analyses of Hoffman et al. (2020) and Locke et al. (2020), our findings align with those previous studies and suggest that the HOLC's Security Maps affect current-day greenspace with decreased greenery in neighborhoods with worse HOLC grades. In addition, tree canopy represents just one facet of greenspace, whereas the NDVI captures all greenspace from grass to trees to shrubs, all of which may be health promoting (Fong et al. 2018; James et al. 2015).

Unlike previous analyses, where other factors related to HOLC grades could have driven the observed associations (e.g., 1940 socioeconomic status), our work compared only HOLC polygons that had similar probabilities of receiving a given HOLC grade and accounted for 1940 census measures, thereby better isolating the relationship between HOLC grade and 2010 greenspace. Furthermore, our work is the first, to our knowledge, to apply TMLE to an analysis involving historical redlining. The TMLE approach incorporates estimation of the treatment model (i.e., propensity score model) to de-bias estimation of the outcome model. This estimation approach is doubly robust in that if either the treatment or outcome model is correctly specified, the estimator will be consistent. The approach has the additional advantage of being able to incorporate machine learning algorithms into model fitting and returning theoretically valid standard error and confidence intervals. Instead of estimating and using propensity scores only within the TMLE algorithm, we estimated the propensity scores outside the algorithm to explicitly assess positivity and limit to a subset of neighborhoods that would not rely on extrapolation outside the area of support.

Table 1. Geographic, 1940s sociodemographic, and 2010 greenspace data among all HOLC polygons overlapping 1940s U.S. Census tracts in 102 U.S. urban areas by HOLC grade.

Characteristic	Row count	HOLC grade			
		A	B	C	D
Total HOLC polygons [*N* (row %)]	4,141	439 (10.6)	1,043 (25.2)	1,637 (39.5)	1,022 (24.7)
2020 Level I ecoregion [*N* (row %)][a]					
Eastern Temperate Forest	3,013	287 (9.5)	714 (23.7)	1,229 (40.8)	783 (26.0)
Great Plains	319	42 (13.2)	72 (22.6)	103 (32.3)	102 (32.0)
Marine West Coast Forest	141	21 (14.9)	46 (32.6)	54 (38.3)	20 (14.2)
Mediterranean California	633	82 (13.0)	204 (32.2)	238 (37.6)	109 (17.2)
Northern Forest	32	4 (12.5)	7 (21.9)	13 (40.6)	8 (25.0)
2020 Census region [*N* (row %)]					
Midwest	1,573	168 (10.7)	363 (23.1)	654 (41.6)	388 (24.7)
Northeast	1,042	85 (8.2)	244 (23.4)	440 (42.2)	273 (26.2)
South	699	75 (10.7)	174 (24.9)	233 (33.3)	217 (31.0)
West	827	111 (13.4)	262 (31.7)	310 (37.5)	144 (17.4)
1940 U.S. Census characteristics [median (IQR)]					
Black (%)		0.6 (1.9)	0.3 (1.3)	0.3 (1.9)	2.1 (15.0)
Completed high school (%)		37.4 (17.5)	27.5 (19.1)	17.7 (15.4)	10.6 (11.6)
Employed (%)		40.0 (5.1)	39.1 (5.1)	38.0 (6.0)	35.2 (7.1)
Foreign-born White (%)		8.6 (8.9)	10.4 (10.1)	13.4 (12.0)	12.6 (16.4)
Major home repairs needed (%)		2.3 (3.6)	3.2 (4.9)	4.6 (6.5)	8.5 (11.0)
Median home value [$1,000s (1940s US$)]		6.3 (4.7)	4.9 (2.9)	3.8 (2.1)	2.7 (2.0)
Non-White (%)		0.9 (2.4)	0.5 (1.6)	0.6 (2.3)	2.7 (15.2)
Population density (thousand persons per HOLC polygon area)[b]		4.8 (10.8)	5.4 (10.3)	4.4 (9.4)	4.8 (11.0)
White (%)		99.1 (2.4)	99.4 (1.6)	99.4 (2.3)	97.3 (15.2)
Without radio (%)		1.0 (1.2)	1.4 (1.6)	2.0 (2.4)	4.6 (7.0)
2010 NDVI [mean (SD)][c]					
Annual average		0.47 (0.09)	0.43 (0.09)	0.39 (0.09)	0.36 (0.10)
Minimum value		0.20	0.16	0.11	0.13
Percentile					
25th		0.41	0.37	0.32	0.29
50th		0.46	0.42	0.38	0.36
75th		0.52	0.49	0.44	0.42
Maximum value		0.69	0.67	0.67	0.68
Summer average		0.57 (0.12)	0.53 (0.13)	0.49 (0.13)	0.46 (0.14)

Note: HOLC-Home Owners' Loan Corporation; IQR, interquartile range; MODIS, MODerate-resolution Imaging Spectroradiometer; NDVI-normalized difference vegetation index; SD, standard deviation.

[a]Two polygons in cities in the Northwestern Forested Mountains (Spokane, WA) and one polygon in the North American Desert (El Paso, TX) ecoregions, both Grade A, were omitted from this table because no other HOLC polygons from these areas were eligible.

[b]1940 population density was calculated using areal-weighted 1940s population of the HOLC polygon area in kilometers-squared.

[c]NDVI were calculated using images from MODIS satellite imagery across all four seasons in 2010.

Historical redlining maps were real estate appraisal tools that reflected institutional forms of discrimination endorsed and perpetuated by those considered experts in the effort to stabilize the real estate market during the Great Depression. Mounting evidence indicates that these historical HOLC risk grade maps contribute to current patterns of worse health outcomes among modern neighborhoods (Krieger et al. 2020; Nardone et al. 2020a, 2020b). Furthermore, historically redlined neighborhoods not only have decreased levels of greenspace but have tended to remain predominantly inhabited by people of color (Mitchell and Franco 2018). Redlined neighborhoods experience other environmental hazards, including elevated levels of diesel particulate exhaust (Nardone et al. 2020a) and hotter temperatures (Hoffman et al. 2020), indicating historical redlining falls well within the purview of environmental justice and thus should be included in such discussions along with those on health disparities.

The belief that racial heterogeneity was a detrimental influence to neighborhood investment, although specifically mentioned on appraisal forms, was not unique to HOLC but, rather, was a widely held policy in federal bodies. For instance, the Federal Housing Administration, tasked with stimulating the private real estate market at the time, would not underwrite insurance on private mortgages that would have desegregated neighborhoods (Federal Housing Administration 1936). Similarly, racially restrictive covenants, which were clauses in home ownership deeds, prohibited the future sale of many homes to people of color (Rothstein 2017). Such racist banking and real estate practices have persisted and are reflected by the fallout of the subprime mortgage crisis, in which

Table 2. Effect estimates of HOLC grade on 2010 NDVI from targeted minimum-loss–based estimation.

Data	Data description	B vs. A	C vs. B	D vs. C
Better HOLC grade	*N* (% of eligible polygons)[a]	380 (86.6)	950 (91.1)	1,536 (93.8)
Worse HOLC grade	*N* (% of eligible polygons)[a]	964 (92.5)	1,484 (90.7)	857 (83.9)
Average annual 2010 NDVI	TMLE estimate (95% CI)	−0.035 (−0.041, −0.029)	−0.022 (−0.028, −0.017)	−0.022 (−0.035, −0.010)
Average summer 2010 NDVI	TMLE estimate (95% CI)	−0.035 (−0.042, −0.029)	−0.026 (−0.033, −0.020)	−0.030 (−0.047, −0.013)

Note: Separate propensity score analyses were conducted to produce data sets for B vs. A, C vs. B, and D vs. C TMLE analyses. Models were adjusted for percentage of non-White residents, Black residents, foreign-born residents, number of people per unit, median home value, percentage of homes needing major repairs, percentage of employed residents, percentage of homes without a radio, percentage of residents who completed high school, census region, ecoregion, and population density. Estimates represent the additive treatment effect. Negative values indicate a decrement in NDVI attributable to worse HOLC grade assignment. CI, confidence interval; HOLC, Home Owners' Loan Corporation; NDVI, normalized difference vegetation index; TMLE, minimum-loss based estimation.

[a]Eligible polygons included any HOLC polygon of equal HOLC grade that had >0% spatial overlap with a 1940s census tract and had at least 1 home in the HOLC polygon.

persons in communities of color, particularly Black and Latino individuals, were disproportionately targeted with predatory loans and foreclosures by banks (U.S. Department of Justice Office of Public Affairs 2011). Although the impacts of these government-sanctioned practices of neighborhood wealth deprivation persist and might shape differences in current greenspace, future analyses should more systematically evaluate the full scope of these discriminatory policies and their implications for modern-day environmental quality and community health outcomes.

Our study had several limitations. First, our NDVI measures were calculated from four different days across 2010: one each in January, April, July, and September. Given that weather varies daily, cloud cover could have affected NDVI levels in some pixels. In addition, the NDVI does not provide an indication of greenspace quality, for example, the use of NDVI-based greenspace measures in places with arid climates may not be reasonable proxies for vicinity to natural environments and their health-related benefits. Second, we limited our analysis to places that overlapped with 1940 census tract boundaries, a limited and likely nonrandom selection of cities that affects the generalizability of our findings. Although our restriction to a subset that has counterparts with similar propensity of being in a particular HOLC grade addresses problems with data extrapolation, it also limits generalizability. It is possible that 1930s greenspace confounded our analyses if, for example, 1930s greenspace decreased the likelihood of receiving a poor HOLC grade. Furthermore, a large amount of time passed between the 1930s assignment of HOLC grades and the 2010 measurement of the NDVI. During this period, multiple policies were passed that likely alleviated and exacerbated the impacts of historical redlining, such as the 1968 Fair Housing Act (U.S. Congress 1968), which explicitly made redlining illegal (Massey 2015). Last, selection bias is a possible result of our analytical approach given that we both excluded HOLC polygons that did not overlap with 1930s census tract boundaries and employed propensity score restriction and matching (56.3% of polygons). Although overall the NDVI was higher in ineligible HOLC polygons, worse-graded HOLC polygons had less greenspace in 2010, similar to the relationship we observed across the eligible HOLC polygons (Tables S5 and S6). Overall, ineligible HOLC polygons and matched polygons had similar HOLC grade, ecoregion, and census region distributions (Table S6).

In conclusion, although redlining is now outlawed, the neighborhood effects of institutional and structural racism outlined by the 1930s HOLC Security Maps appears to persist. We observed that worse HOLC grade assignments were associated with reduced present-day greenspace. Given that historical and current-day access to greenspace has been inequitable due to discriminatory government-sanctioned practices, future policies should, with the input of local leaders, strive to expand availability of such a health-promoting amenity in communities of color that have experienced racist redlining.

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