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The racial inequity of park visitation behavior in the post-pandemic era

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ABSTRACT

The COVID-19 pandemic has exacerbated pre-existing racial disparities in park usage. Although numerous studies have reported a widened racial inequity in park visitation during the pandemic, it remains unclear how this inequity has dynamically evolved in post-pandemic era. In this study, using nationwide location-based mobile data from SafeGraph's Monthly Patterns dataset and the linear mixed effects model, we analyzed four-year longitudinal change (2018–2021) in park visitation behaviors among racially distinct neighborhoods and examined whether neighborhood greenness moderated these disparities in the United States. The results demonstrate that: (1) racial inequity in park visitation has continued to widen over the two-year pandemic period; (2) while park visitation across all groups has gradually returned to and even surpassed pre-pandemic levels, Black-majority groups consistently exhibited lower visit counts and fewer visited parks than Black-minority groups; and (3) neighborhood greenness significantly mitigates racial disparities in park visitation, with higher greenness levels associated with reduced inequity. These findings point out the potential impact of neighborhood greenness on alleviating racial inequity in park visits.

1. Introduction

1.1. Green spaces and the COVID-19 pandemic

The COVID-19 pandemic has underscored the significance of green spaces on a global scale. During the pandemic, governments implemented varied social-distancing policies (e.g., lockdowns, and closure of indoor public recreational and sporting facilities) to mitigate the transmission of the virus (Flaxman et al., 2020; Lai et al., 2020). These measures, while effectively containing the pandemic through restricting human mobility and close contact (Bo et al., 2021; Glogowsky et al., 2021; Wellenius et al., 2021), have also elevated public green spaces into an irreplaceable position as "shelters" or "lifelines" for urban dwellers, offering them a respite from stress and helping them maintain physical and mental well-being (Brooks et al., 2020; Marroquín et al., 2020; Pfefferbaum & North, 2020; Pouso et al., 2021).

Parks, greenways, or trails have been recognized as comparatively lower-risk alternatives to address the soaring need for respite, recreation, and distanced socializing in the face of pandemic-enhanced challenges. Many prior studies have documented a significant increase in visits to green spaces since the pandemic outbreak (H. Burnett et al., 2022; Geng et al., 2021; Lu et al., 2021; Venter et al., 2020). Those with more natural/green areas and open spaces (fisher & Grima, 2020; Grzyb et al., 2021; Korpilo et al., 2021), and located nearby residents' homes (Korpilo et al., 2021; Ugolini et al., 2020; A. Yang et al., 2021) were preferred. Such green spaces, on the one hand, offered desirable outdoor recreational areas for residents to engage in leisure and physical activities without being overcrowded, thereby helping them stave off the increased risk of infection; on the other hand, and perhaps more importantly, people could benefit from the well-established health benefits of green space exposure (James et al., 2015; van den Bosch & Ode Sang, 2017). The increased contact with nature could not only mitigate against negative emotions (e.g., depression, insomnia, or generalized anxiety disorder) under stringent social-distancing policies (Dzhambov et al., 2021; Pouso et al., 2021; Spano et al., 2021), but also promote the maintenance of physical activity levels (Yang et al., 2021), and potentially reduce the infection rate and mortality during the pandemic (Jiang et al., 2022; Wang et al., 2021).

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1.2. Racial inequity of green spaces and the COVID-19 pandemic

However, racial disparities in access to green spaces have long existed, particularly in the United States (US). Evidence has shown that disadvantaged racial groups, especially black individuals, typically experience limited green spaces such as parks and other types of outdoor recreation resources in their communities in the US (Astell-Burt, Feng, Mavoa et al., 2014; Nesbitt et al., 2019; Watkins & Gerrish, 2018). A report by the Trust for Public Land has claimed that parks located in White-minority communities are almost five times more crowded than those in White-majority ones (The Trust for Public Land, 2020). In addition to the park availability, inequities in the park quality have been a prevalent issue and widely existed, with the disadvantaged groups commonly experiencing dismal park amenities with low maintenance levels and more safety issues in their neighborhood parks (Rigolon, 2016; Rigolon et al., 2018).

These disproportionate disparities in park availability and quality have become even more challenging in the context of the global pandemic. The pandemic may have further exacerbated the inequity in green space usage. Several studies have already identified a widened racial disparity in urban park use in comparison to non-pandemic periods (Alba et al., 2022; Astell-Burt & Feng, 2021; Pipitone & Jovic, 2021). Individuals of white race and high income have shown an evident increase trend in their frequency of park visits and reported a higher level of satisfaction with local green spaces compared with colored and low-income populations since the pandemic outbreak (Alba et al., 2022; Pipitone & Jovic, 2021). The change in time spent in parks also presented significant disparities among different groups, with respondents of lower social class having shorter dwell times (Hannah Burnett et al., 2021). One contributing factor is the uneven distribution of park quality across neighborhoods. Studies have shown that parks in predominantly Black communities are often smaller, more crowded, and less well maintained compared to those in White-majority areas (Nesbitt et al., 2019; Rigolon et al., 2018). However, some studies reported a contrary result that the pandemic did not result in more severe park use inequity among vulnerable groups (Scott, 2021), as alternative green spaces, such as tree-lined streets, could compensate for the need for outdoor activities during the pandemic.

1.3. The moderating effect of green spaces on racial disparity

Established evidence has indicated that green spaces could significantly alleviate the racial disparity in the health domain (Lee et al., 2023; Lu et al., 2021; Rigolon et al., 2021; Spotswood et al., 2021). During the pandemic, people living in areas with a higher ratio of green spaces and better green space accessibility saw lower levels of racial inequity in both infection and mental health status (Lee et al., 2023; Lu, Chen, et al., 2021). Similar findings could also be found in the non-pandemic period for socioeconomic status (SES) disparities. Mitchell et al. have reported that green spaces could moderate the inequity of all-cause and circulatory disease mortality related to income deprivation, with populations who live in greener areas having lower inequity levels (Mitchell & Popham, 2008). All these findings suggest that socially disadvantaged groups tend to obtain more marginal health benefits from green spaces than the advantaged ones. In terms of the mechanisms behind it, existing studies have mainly discussed the health effects of green spaces, such as the mental restorative effects, improving air quality, or promoting physical activity (Lee et al., 2023; Lu, Chen, et al., 2021; Moran et al., 2021). However, there is a key step that may have been overlooked, that is more green space usage is the most direct way to gain benefits for disadvantaged groups, which means that more green spaces may mitigate the disparity in green space usage, thus moderating the disparity in health-related domain. Nevertheless, such conjecture about the moderation role of green spaces on racial inequity in green space usage has not been fully verified in prior studies.

1.4. Research gaps and hypothesis

Despite a growing number of studies on racial inequity of green space usage during the pandemic, the findings are still mixed and insufficient to provide solid evidence on this issue, as the majority of them used survey data with limited sample sizes, geographic scope, and single selected time node. The evidence derived from a larger population on a national scale is still scarce. Second, as the COVID-19 crisis gradually winds down, people may return to normal life after over three years of struggling. There is a major research question warranting further exploration. Does the increased inequity of green space usage persist or return to pre-pandemic level, or become even more severe as the pandemic recedes? There is currently no research tracking and exploring such long-term dynamic changes in inequity from the beginning to the later stages of the pandemic. Third, numerous evidence have shown that the greenness level could moderate the racial inequity in health, with racial minorities having more marginal benefits from green spaces. However, it remains unclear whether the direct mechanism behind is the moderation effect of greenness on racial inequity in green space usage. Do those greener neighborhoods experience fewer racial inequity issues while less green ones suffer more? Based on the research questions and gaps above, we tentatively proposed two research hypotheses accordingly:

Hypothesis 1. (*Park usage inequity gradually returns to pre-pandemic levels as the pandemic recedes.*) *Many prior studies have identified that the widened inequity of green space usage may be largely due to the pre-existing disparities of green space resources* (e.g., *crowded, poor facilities and maintenance), as well as reduced accessibility caused by containment policies, which further hinder green space usage by vulnerable populations* (Alba et al., 2022; Pipitone & Jovic, 2021). *However, with the widespread availability of COVID*-19 *vaccines and in-depth recognition of the virus, coupled with the decrease in its virulence, people's attitudes and perceptions towards the pandemic have undergone a significant transformation. Human mobility has also gradually returned to pre-pandemic levels after three years of struggling, as policies have shifted from strict lockdowns or stay-at-home orders to more relaxed measures* (Wu et al., 2023; Yabe et al., 2023). *Against such a returning backdrop, the extra barriers of park visitation caused by the pandemic may gradually disappear, thus, we hypothesize that the exacerbated inequity of green space usage may also gradually rebound to pre-pandemic levels as the pandemic winds down.*

Hypothesis 2. (*The inequity recovers better and faster in neighborhoods with more green resources.*) *As we mentioned above, the inequity of green resource distribution makes a major contribution to the disparity in green space usage, even if there are also some individual factors such as preference and perception of green space, and transport opportunity. Disadvantaged racial groups living in neighborhoods with more green spaces and better accessibility have a better chance to visit green spaces, compared with those living in neighborhoods with fewer green spaces* (Lee et al., 2023). *Pre-existing evidence has also indicated that green spaces could reduce racial inequity in health* (Lee et al., 2023; Lu, Chen, et al., 2021). *This may be caused by the moderation effect of green space on racial inequity in its usage. In a nutshell, the advantages of green resources could help alleviate the inequity of green space usage. Conversely, disadvantaged racial groups living in less green neighborhoods may face greater challenges in visiting green spaces during the pandemic, potentially further widening the racial inequity in park usage. Hence, our second hypothesis is that the inequity issues may be moderated by the green resource levels, with more green areas experiencing narrower racial inequity in green space usage and vice versa.*

To address the above gaps and test the hypotheses, we leveraged location-based mobile big data that capture human mobility patterns across space and time. Compared to traditional surveys or official visitation records, mobile data enables the monitoring of park visitation behaviors at a national scale with high spatial and temporal resolution. This approach is particularly valuable in the context of the COVID-19 pandemic, where individual-level behavior and park usage patterns may shift rapidly and vary significantly across neighborhoods. The data allow us to observe actual visitation dynamics across over 200,000 census block groups in the contiguous US, making it possible to assess both the temporal evolution of racial inequity and the potential moderating role of neighborhood greenness.

Specifically, we first investigated how the racial inequity in park visitation changed since the pandemic outbreak (January 2020-December 2021) in comparison to the non-pandemic periods in the US. Second, we examined if such racial inequity could be moderated by neighborhood greenness, with greenery areas experiencing lower levels of inequity issues over different pandemic periods. The potential mechanisms underlying the changing patterns and moderation effects were also discussed in this study.

2. Methods

2.1. Study extent

This study encompasses all Census Block Groups (CBG), which serve as the smallest geographic entity for census data publication in the US, as the basic research units. A total of 215,217 CBGs were included across the contiguous US after excluding those without any populations, as shown in Fig. 1. All park visitation variables, sociodemographic characteristics, and greenness were calculated at the CBG level in our analysis.

2.2. Park visitation data

The visitation data is obtained from SafeGraph's Monthly Patterns dataset, which covers the period from January 1, 2018, to December 31, 2021. SafeGraph is a data service company providing approximately 4.4 million Points of Interest (POIs) derived from nearly 10 % of anonymous

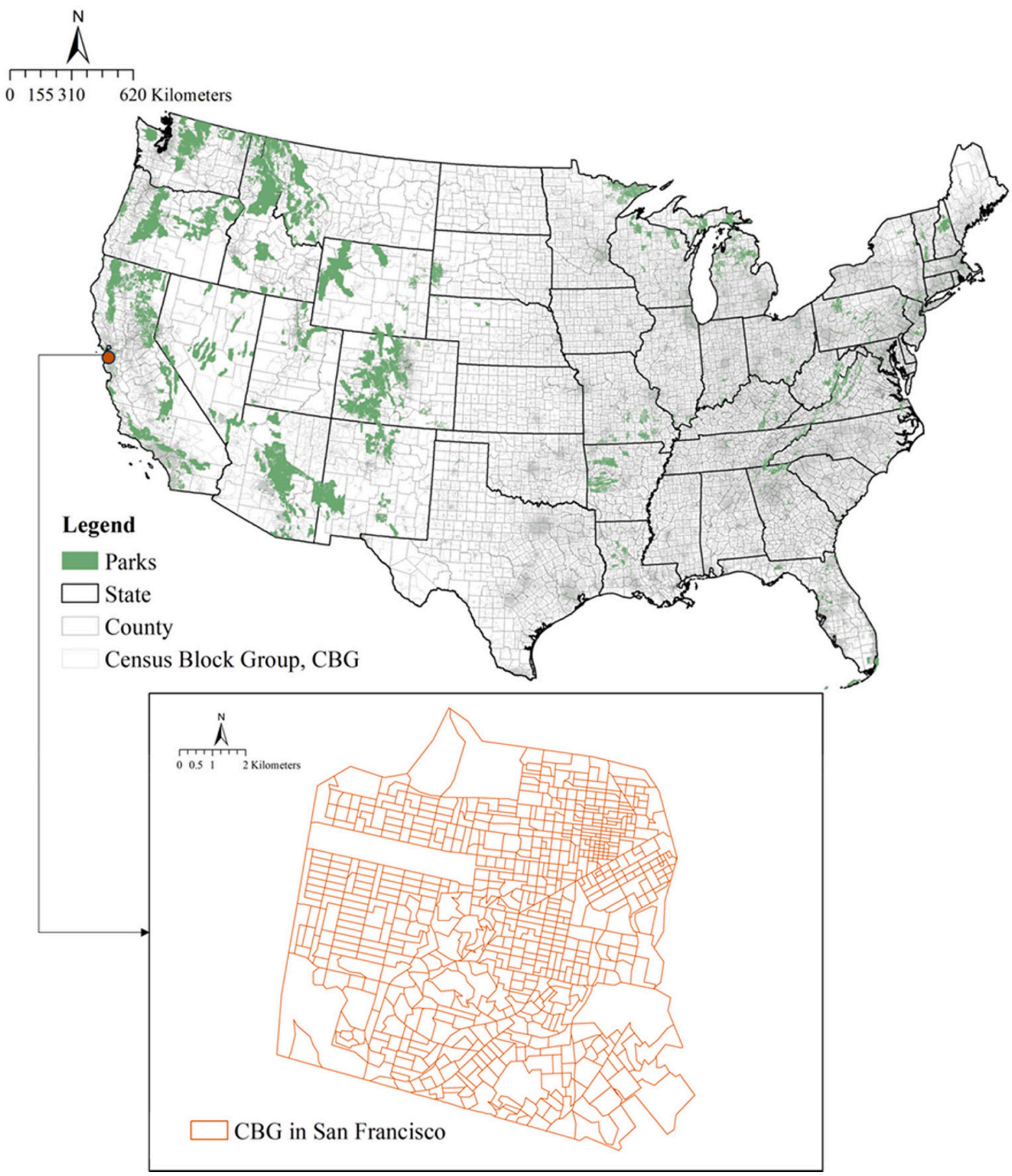


Fig. 1. Study area (Note: San Francisco is shown here as a representative area to illustrate the spatial resolution of CBG units. The actual analysis covers all CBGs across the continental US).

mobile devices in the US (Safegraph, 2022). The Monthly Patterns dataset contains aggregated visitation information for each POI (e.g., POI name, visit date range, visitor home, and counts) from a panel of mobile devices monthly. As shown in Table 1, “Placekey” is the unique and persistent ID assigned to each POI. The “Visitor_home_cbg” field includes the home location of devices (from which CBG) and the corresponding visitor counts. SafeGraph defines home location as the common nighttime location of devices in CBGs, which is determined by analyzing six weeks of data during nighttime hours (between 6p.m. and 7 a.m.). All visitation data is aggregated at the POI or CBG level to protect the privacy of mobile users.

There are four steps to acquire the park-related visitation data at the CBG level, as shown in Fig. 2. First, we identified the park-related POIs from the original dataset. Merely using a single POI as a park destination could be misleading because many large parks contain multiple POIs (e.g., park baseball field, park jogging trail). To address this issue, we utilized the Trust for Public Land’s ParkServe database (The Trust for Public Land, 2022), which contains boundaries of 210,250 parks in the US, and extracted POIs within the park boundaries as park-related POIs. Second, we extracted park-related visitation data at the POI level from the monthly Patterns dataset. The data of POIs within one park were aggregated because each park may have one or more visitation records. Third, the “Visitor_home_cbg” field was used to extract all the Origin-Destination (Home CBG-Park POI) trip pairs, along with corresponding visitor counts. Fourth, we aggregated the visitor counts of all O-D pairs, as well as the number of visited parks, based on the home CBG ID, year, and month. Monthly park visitation data originated from each CBG, including the number of total monthly park visitors and visited parks, was obtained from January 2018 to December 2021. Further, since the original dataset only includes visitor counts, we further calculated the normalized park visit counts based on the methodology developed by the Safegraph team (Eugene, 2021).

2.3. Measures

2.3.1. Change of park visitation at CBG level

We utilized two metrics to quantify the level of park visitation during the pandemic: The change in 1) park visit counts, and 2) the number of visited parks in comparison to the non-pandemic period. Both of these metrics were calculated at the CBG level. We first established the baseline value for these two metrics by calculating their monthly mean in 2018 and 2019. Then, the year-over-year (YOY) park visitation change was calculated by dividing the difference between the current monthly value (2020 and 2021) and the corresponding monthly baseline value by the baseline value. Such measurement not only ensures a more stable baseline value but also eliminates the effect of seasonal changes such as temperature and precipitation. The formula is given by:

$$YOY_{ij} = \frac{CPV_{ij} - BPV_{ij}}{BPV_{ij}}$$

where YOY_{ij} denotes the year-over-year (YOY) park visitation change (including park visit counts and the number of visited parks) in CBG i and month j; CPV_{ij} is the current monthly value (2020 and 2021) for CBG i and month j; BPV_{ij} is the monthly baseline value (mean value of 2018 and 2019) for CBG i at month j. This YOY measure can provide a full and clear picture of how park visitation behavior changes over a nearly two-year pandemic period at fine-scale geographic units, with negative values indicating a decline and positive values indicating an increase.

2.3.2. Racial inequity in park visitation

We measured the racial inequity by the disparity of park visitation indicators among CBGs with varying race groups. The racial demographic data is obtained from the 2020 US Census Bureau at the CBG level (Census, 2020). The proportion of the Black or African American population (hereinafter referred to as the Black population) in each CBG was calculated (see details in Section 2.5). To enable a more intuitive comparison, we further categorized all CBGs into four groups based on the quartiles of Black population proportion, ranging from Group 1 (least Black) to Group 4 (most Black).

For the purposes of analysis and visualization, we define Black-majority CBGs as those where more than 50 % of residents identify as Black (Groups 3 and 4), and Black-minority CBGs as those where Black residents constitute less than 50 % of the population (Groups 1 and 2). A similar definition applies to White-majority and White-minority CBGs, based on the proportion of White residents. All figures illustrating the longitudinal change in park visitation in the Results section are based on this classification.

2.3.3. Greenness

To test the second hypothesis, we quantify the neighborhood greenness by the mean Normalized Difference Vegetation Index (NDVI) at a 1500 m buffer from home CBGs. This distance reflects a reasonable walking range and has been adopted in similar urban park access and exposure studies (Geneshka et al., 2025). The NDVI data was calculated from the Landsat-8 satellite images with 30 m spatial resolution, which offers a balance between spatial precision and consistent national coverage.

2.3.4. Covariates

Infection case

Many studies have identified that infection risk is a critical factor affecting people’s park visit intention and cognate activities during the COVID-19 pandemic (Chan et al., 2020; Landry et al., 2021; Ma et al., 2021). People might intentionally reduce park visitation when the number of infection cases surges significantly. We adopted the monthly mean of new infection cases at the county level as a measure of the pandemic severity to control the potential effect on park visitation change. The infection data is obtained from the Centers for Disease Control and Prevention (2020) which is the most fine-scale nationwide dataset in the US.

Policy stringency

The varying containment policies coping with the pandemic may also significantly restrict park visitation behaviors (Ding et al., 2022; Geng et al., 2021). Human mobility has been severely affected by strict stay-at-home orders, and some parks have been temporarily closed along with the policies. Hence, we added the monthly mean stringency index derived from the COVID-19 Government Response Tracker/OxCGRT dataset (Hale et al., 2021) to control the impact of policies. This index considers seven types of containment policies (i.e., closing schools, closing workplaces, public event cancellations, gathering restrictions, closing public transport, stay-at-home requirements, and restrictions on internal movement and international travel) at the state

Table 1
Examples of monthly patterns dataset from SafeGraph.

Placekey	Location_name	Date_range_start	Date_range_end	Visitor_home_cbg
22q-222@627-s8r-jy9	Big Bend National Park	2021–04-01 T00:00:00–04:00	2021–05-01 T00:00:00–04:00	"360610112021": 603, "460610112021": 243, "560610112021": 106, "660610112021": 87, "660610112021": 51
22j-222@5pw-5zw-mzf	Sanborn County Park	2021–04-01 T00:00:00–05:00	2021–05-01 T00:00:00–05:00	"360610112030": 9872, "880610112021": 8441, "569610112020": 5671, "160610112041": 2296, "980610112021": 1985

Note: This table shows only some of the key fields. For a more comprehensive table, see (https://docs.safegraph.com/docs/weekly-patterns).

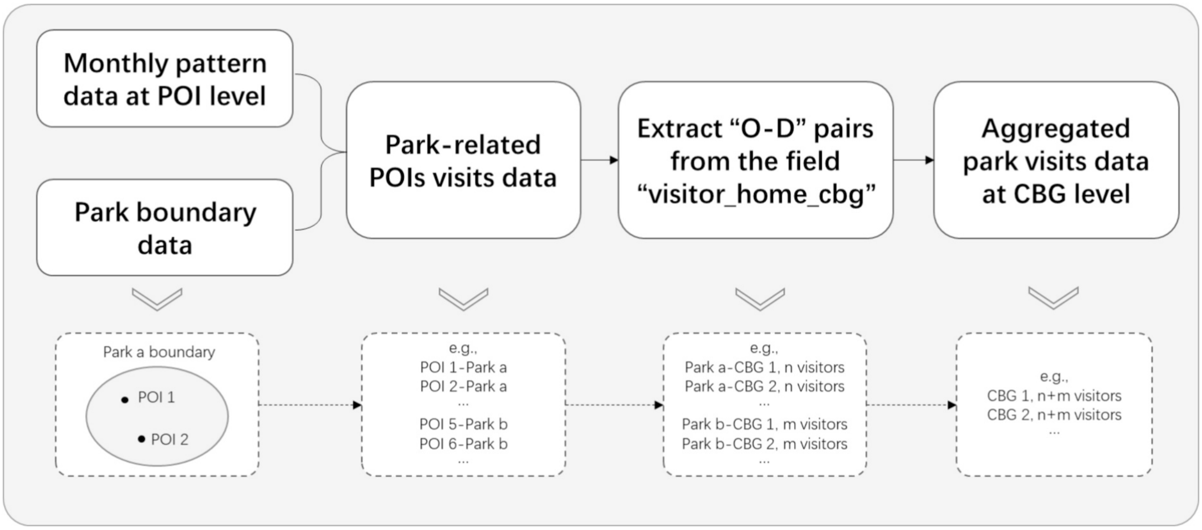


Fig. 2. Flowchart of processing park visitation data.

level, which have been widely used in prior studies.

Vaccination

Evidence has shown that the emerging vaccines since 2021 enhance people's sense of security and promote the restoration of human mobility (Wu et al., 2023), which may also influence their intention for park visitation. We included the monthly vaccination rate (completing a 2-dose injection) at the county level in our models. The vaccination data is also obtained from the Centers for Disease Control and Prevention (2020).

Sociodemographic variables

We also considered the potential impact of individual demographic factors (e.g., gender and age) on park visitation change. The percentage of females and elders (aged over 65 years), and median income in each CBG were included in our analysis.

2.4. Statistical analysis

To test hypotheses 1 and 2, we conducted two analyses including direct data visualization and mixed effects model analysis. We first plotted the dynamic change of YOY park visitation among four race groups during the pandemic. Both park visit counts and the number of visited parks were visualized for comparison.

Further, given the repeated measurements of park visitation at the CBG level across multiple time points, we applied a linear mixed-effects model to account for the nested data structure. CBGs were modeled as random intercepts to capture between-group variability and control for temporal autocorrelation. This approach allows for robust estimation of group-level effects while properly handling the hierarchical structure of the dataset. The park visit counts and the number of visited parks were modeled separately.

In Model 1, we examined the role of time (month), black-race ratio, and neighborhood greenness on the YOY park visitation change without controlling for any covariate. In Model 2, we added the interaction terms between time, race, and greenness, including three two-way interaction terms (race × time, greenness × time, and race × greenness) and one three-way interaction term (race × time × greenness) to test Hypotheses 1 and 2. Race × time term accounts for the racial inequity changes of park visitation over time, greenness × time accounts for the effect of greenness change over time, race × greenness accounts for the racial inequity changes among different levels of greenness, and race × time × greenness accounts for the racial inequity changes among different levels of greenness over time. For Model 3, we further added all covariates (e.g., infection case, policy stringency, vaccination, population density, gender, and age). All of the explanatory variables were centered and scaled in the models. The variance inflation factor (VIF) test was adopted to identify multi-collinearity, and the vaccination variable was excluded from our models with a VIF value greater than 4.

3. Results

3.1. Longitudinal change of racial inequity in park visitation

Fig. 3 plots the YOY changes in park visit counts among four race groups. Overall, the racial inequity of park visitation has widened and persisted since July 2020, with an average increase of 12.4 percent compared with the baseline in the Black-majortity group (dark blue line) and an average increase of 12.4 percent in the Black-minority group (light blue line). The summary statistics of variables among different race groups are presented in Table S1.

Detailly, the number of park visit counts has drastically decreased during the first wave of the pandemic (March to May 2020). Subsequently, a recovery trend in park visitation could be observed across all race groups. However, there was no significant distinct disparity between groups before July 2020. Conversely, starting at this time point, the differences between the groups began to emerge and gradually show a clear pattern along with the progress of the pandemic, even though the overall level of all groups has surpassed the pre-pandemic level. The Black-majority groups (Groups 3 and 4), defined as CBGs where more than 50 % of residents identify as Black, generally exhibited lower year-over-year (YOY) change ratios in park visit counts compared to the Black-minority groups (Groups 1 and 2), where Black residents comprise less than 50 % of the population. Moreover, the gap between these groups gradually widened over the course of 2021.

Likewise, in Fig. 4, change in the number of visited parks has shown more clear and similar patterns with the park visit counts, with an average of 3.7 percent increase in the Black-majority group and 11 percent increase in the Black-minority ones in comparison to the non-pandemic period. In general, the YOY change in the number of visited parks among Black-majority groups has been consistently lower than those of Black-minority groups since the pandemic outbreak. The between-group differences remained until the end of year 2021. Moreover, the recovery trend for some groups has been more distinct since July 2020 than for others. The Black-minority groups (groups 1 and 2) have recovered to, and even surpassed the pre-pandemic level, whereas the Black-dominated groups (groups 3 and 4) have remained below or near pre-pandemic levels. Hence, the widened racial inequity of park visitation caused by the pandemic did not diminish with the pandemic evolution, which is contrary to Hypothesis 1. We also plotted the actual

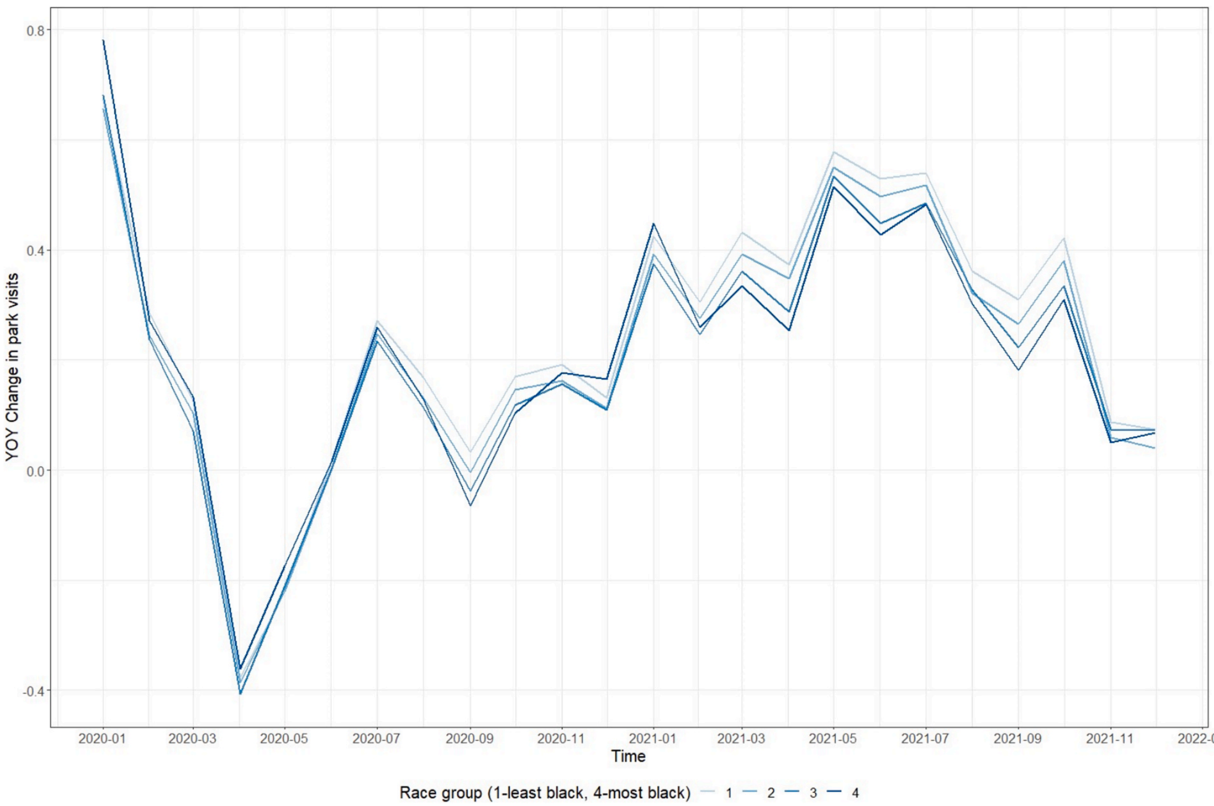


Fig. 3. YOY change in park visit counts among different race groups.

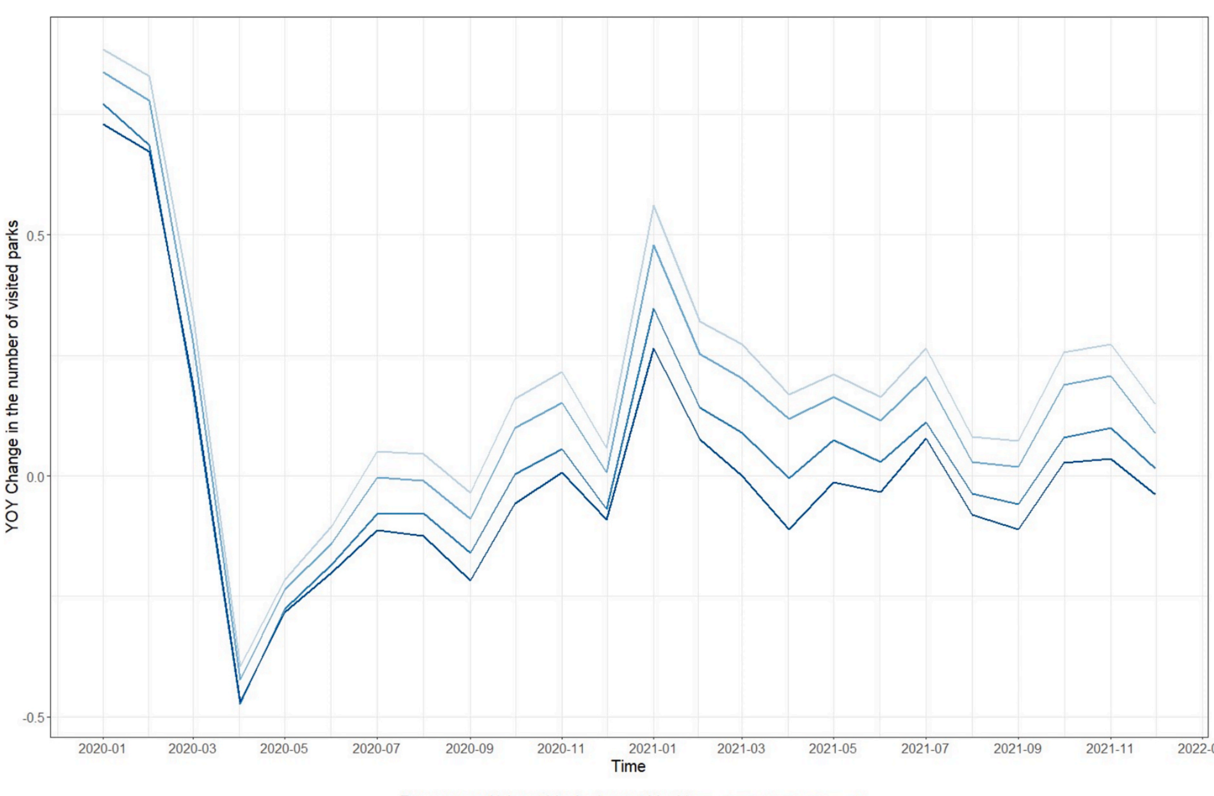


Fig. 4. YOY change in the number of visited parks among different race groups.

park visit change and the number of visited parks changed in 2020 and 2021 compared to the baseline value in Figs. S1-S2 for reference.

3.2. *The moderation effect of greenness on racial inequity in park visitation*

Since the regression results of park visit counts and the number of visited parks are almost identical, we mainly reported the results of park visits, as shown in Table 2. See Table S2 in the supplementary material for the results of park numbers. Table 2 presents the analytical results pertinent to the association between YOY park visit changes and explanatory variables, including race, greenness, time, and the interaction terms between them. In Model 1, the black race ratio ($\beta = -0.015$, p < 0.001) was negatively related to park visit counts, indicating that the more black population in CBGs, the lower changes in park visitation. The neighborhood greenness ($\beta = 0.041$, $p < 0.001$) was positively related to park visit counts. In general, CBGs with fewer black population and higher greenness levels have more park visits. Such a relationship persists when including the interaction terms in Model 2 and covariates in Model 3.

In Model 2 and Model 3, we added both two-way and three-way interaction terms to test our two hypotheses. To better understand these significant interaction terms with both positive and negative coefficients, we followed the spotlight analysis method and picked three representative values (mean value, and mean value plus or minus standard deviation ($\pm$ SD) of corresponding variables, respectively) to plot the estimated slopes of these interaction terms. In Fig. 5(a), the significant interaction term of race and time ($\beta = -0.026$, $p < 0.001$) shows that compared with Black-majority groups, the park visit counts

Table 2
Mixed effects regression modeling results for YOY changes in park visit count.

	Model 1-Initial model	**Model 2-Interaction model**	**Model 3-Full model**
Predictors	Estimates	Estimates	Estimates
(Intercept)	0.016*** 0.014 – 0.018	0.016*** 0.014 – 0.018	0.01*** 0.008 – 0.012
Time (month)	0.122*** 0.121 – 0.123	0.123*** 0.122 – 0.123	0.084*** 0.083 – 0.085
Race (black)	−0.015*** −0.016 – -0.013	−0.014*** −0.016 – -0.012	−0.051*** −0.053 – -0.049
Greenness	0.041*** 0.040 – 0.043	0.041*** 0.040 – 0.043	0.046*** 0.045 – 0.048
Race × Time		−0.028*** −0.029 – -0.027	−0.026*** −0.027 – -0.025
Greenness × Time		0.010*** 0.009 – 0.011	0.009*** 0.008 – 0.010
Race × Greenness		0.000 −0.002 – 0.002	−0.002*** −0.004 – -0.000
Race × Greenness × Time		0.009*** 0.008 – 0.010	0.013*** 0.012 – 0.014
Policy stringency			−0.197*** −0.198 – -0.196
Infection case			−0.013*** −0.014 – -0.012
Population density			0.018*** 0.016 – 0.020
Elders			−0.029*** −0.030 – -0.027
Female			−0.001 −0.003 – 0.001
Income			−0.103*** −0.105 – -0.101

Note: 95% confidence intervals are given in brackets. *** denotes a statistical significance level of 5% or better.

recovered more sharply in Black-minority groups, which implied that the racial inequity of park visitation has gradually widened along with the pandemic progress. This finding was in line with Fig. 3, also contrary to Hypothesis 1. Likewise, the significant interaction term of greenness and time ($\beta = 0.009$, $p < 0.001$) in Fig. 5(b) also suggests that areas with lower greenness levels experienced a slower recovery in park visitation over time. The significant interaction term of race and greenness ($\beta =$ -0.002, $p < 0.001$) shown in Fig. 5(c) indicates that the less-white group was able to have more park visits with the increase in neighborhood greenness. In other words, the higher greenness levels could higher marginal effect on the white-less group, and effectively alleviate the racial disparity in park visitation. The results are in line with Hypothesis 2.

In Fig. 6, the significant interaction term of race, greenness, and time ($\beta = -0.003$, $p < 0.001$) indicated that racial inequity could be narrowed in CBGs with higher levels of neighborhood greenness. In less green CBGs, the Black-majority groups have less park visit counts than the Black-minority groups, and the racial disparity among groups has widened along with the pandemic. In more green CBGs, the park visits of each group were still in the same order, but the disparity between the groups decreased with the increase in greenness levels.

4. Discussion

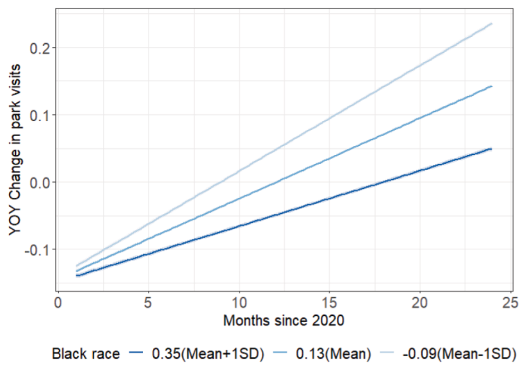
This study conducted a two-year longitudinal analysis at a fine CBG scale to explore how the racial inequity of park visitation dynamically changed in the post-pandemic era across the contiguous US. Such a large-scale and long-term analysis provides more solid evidence for this line of issues. The major findings have been interpreted in the following sections.

Finding 1:

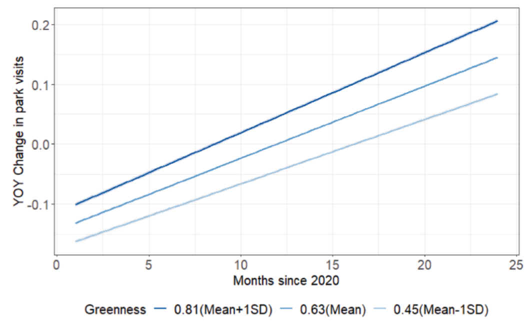
Based on the collected mobile data, racial inequity in park visitation has significantly widened during the pandemic, with the Black-minority groups maintaining more park visit counts and park numbers in comparison with the Black-majority groups. This observation aligns with several prior studies that have reported increased disparities in park usage through survey data since the outbreak of COVID-19 (Alba et al., 2022; Astell-Burt & Feng, 2021; Pipitone & Jovic, 2021). To explain this widening disparity between racial groups in park usage, we proposed three mechanisms that focus on broader structural and contextual disparities rather than individual psychological preferences.

First, differences in COVID-19 risk perception may have driven divergent park visitation behaviors. The Black population tends to perceive higher infection risks, partly due to the crowded and lower-quality park conditions in their neighborhoods (Fagerholm et al., 2021; Khozaei et al., 2021; Lopez et al., 2021; Ugolini et al., 2020). Parks in predominantly Black communities are reportedly four times more crowded than those serving White populations (The Trust for Public Land, 2020), which could reinforce fear and discourage park visits. Moreover, the exposure to the pandemic with a higher infection rate and high public-contact jobs among the colored population may further exacerbate their risk perception (Lu, Chen, et al., 2021; Spotswood et al., 2021). One study has pointed out that the infection rate for black individuals was approximately twice that of white ones among the 135 most urbanized counties in the US (Lu, Chen, et al., 2021). The fear of infection, coupled with the crowded environments, may further discourage ethnic minorities and lead to inertia in their reluctance to conduct outdoor activities in parks.

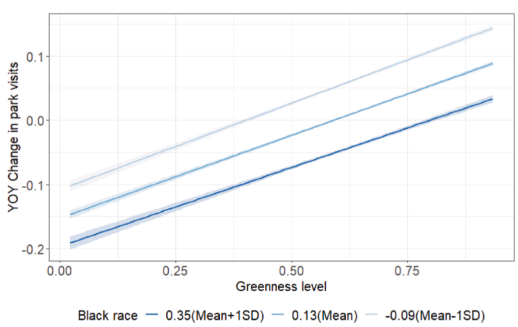
Second, the diminished ability to access parks among ethnic minorities could also account for such widened racial inequity. The unprecedented economic impact of the pandemic has disproportionately fallen on vulnerable groups, including the low-income and colored populations, resulting in severe economic and unemployment pressure (Baena-Díez et al., 2020; Chen & Krieger, 2021). Despite the established benefits of visiting parks during the pandemic, it still takes economic resources and dispensable time to engage in such behavior, which the



(a) Interaction effect between race and time



(b) Interaction effect between greenness and time



(c) Interaction effect of race and greenness

Fig. 5. Two-way interaction effect between race, greenness, and time.

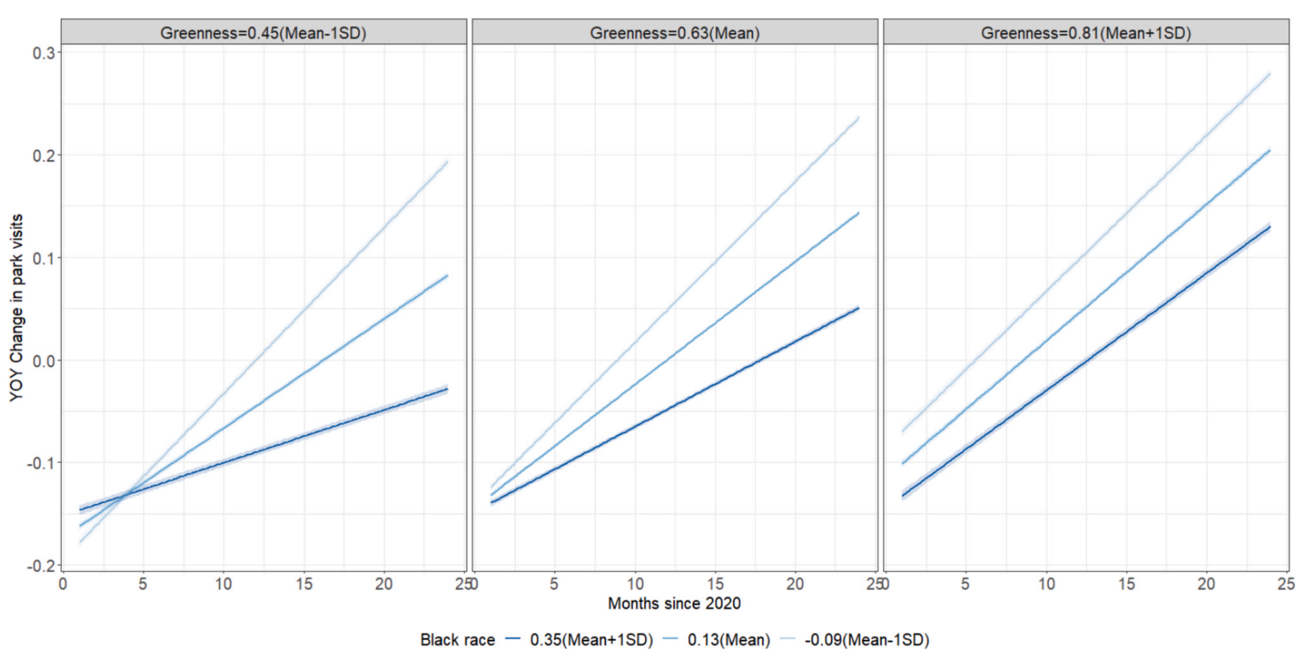


Fig. 6. Three-way interaction effect between race, greenness, and time.

vulnerable populations lack (Alba et al., 2022; Pipitone & Jovic, 2021). As a result, these costs may hinder ethnic minorities who suffered severe economic loss amidst the pandemic period from accessing parks, and such barriers may persist along with the economic impact. Besides, the worse accessibility of the parks serving the colored population may also result in longer travel distances and time, thereby further increasing the travel cost (Rigolon & Flohr, 2014). Though there are also studies indicating that the Black tend to live closer to parks, the changed preference for natural and greener parks during the pandemic (Korpilo et al., 2021; Lenaerts et al., 2021; Lu, Zhao, et al., 2021; Ugolini et al., 2020; Venter et al., 2020; A. Yang et al., 2021), which are generally located in *peri*-urban or suburban areas, may also enlarge the travel distance and time, which are harder for the Black population to afford. A study in the US also confirmed that visitation volumes of national parks sharply declined if the non-white communities were situated further from national parks (Alba et al., 2022).

Third, the long-term imbalance of parks and demand may contribute to a lower level of park visitation among Black-majority groups. Evidence has shown that the demand for parks and green spaces significantly increased, especially when stringent social distancing policies (e.g., the closure of indoor recreation facilities) were implemented since the pandemic outbreak (Zhu & Xu, 2021). Nevertheless, the colored communities have only half as many parks as the white ones (The Trust for Public Land, 2020). With regard to the maintenance level and facilities, the racial disparity is also evident presenting a polarized pattern among parks in the US (Rigolon, 2016; Rigolon et al., 2018). Hence, parks serving the vulnerable population may not well satisfy the increasing demands, or even hinder park visitation behavior in times of pandemic crisis.

Finding 2:

The widened racial inequity in park visitation has continued to exist and become even larger in the post-pandemic era, even though the overall level of park visitation of some groups has surpassed the non-pandemic period. This finding is surprisingly contrary to Hypothesis 1 that the park visitation inequity may gradually rebound to pre-pandemic levels along with the recovering human mobility in the post-pandemic era (Yabe et al., 2023). Although this is one of the few studies discussing the longitudinal change of park use inequity and there is no consistent evidence up to now, based on explanations in finding 1, we offer two possible explanations.

First, the rising inflation in the post-pandemic era has continued to affect the disadvantaged groups. According to the Global Wage Report 2022–2023 (International Labour Organization, 2023), the increasing cost of living caused by inflation has the greatest impact on lower-income populations and the inflation is also biting into the purchasing power of minimum wages. Considering the profound economic shock of the COVID-19 pandemic, the economy is unlikely to recover any time soon, especially for the disadvantaged population. It may still be hard to afford the high cost of park visitation behavior as we discussed in the explanation in Finding 1. Second, a prolonged mismatch of resources and needs may consequently lead to a forced reduction in willingness to access parks, thereby continuously influencing the park visitation behavior of vulnerable groups. A survey study conducted in the US found that people living in the lowest-income communities (Pipitone & Jovic, 2021) were far less likely to consider green spaces as necessities than those living in higher-income areas since the pandemic. Lack of access to green space could lead to a weaker sense of belonging or perception and lower demand for parks. Such impacts may persist, contributing to the continuously widening racial disparity in park visitation. In summary, the impact of disparity in green resource distribution (accessibility, quantity) may disproportionately exacerbate dsadvantaged groups when facing the overwhelming pandemic.

Finding 3:

The neighborhood greenness could significantly alleviate the racial disparity in park visitation during the pandemic. This finding is in line with our hypothesis 2, that the racial inequity of park visitation is lower in areas with higher greenness. There are two explanations for this finding, 1) greenness has a promotion effect on park visitation behaviors, and 2) such effect is particularly strong among Black-majority groups. First, the park visiting promotion effect of greenness is consistent with prior studies that have indicated the availability of green space or green residential environment could increase the likelihood of park and nature usage (Maat & De Vries, 2006). People living in neighborhoods with higher levels of greenness tend to visit parks more frequently, which means that they are more likely to maintain the habits of conducting outdoor activities including visiting parks. Our results shown in Fig. 4(b) could also confirm this idea, with greener neighborhoods maintaining a higher level of park visitation.

Nevertheless, the potential influence of self-selection in the residential choice process is hard to exclude and prove (Lu et al., 2018; Mokhtarian & Cao, 2008). To be specific, people are more likely to find a living environment that matches their personal needs, including their preference for greenness, and may display a strong interaction with that environment on their initiative (Maat & De Vries, 2006). Though such content is beyond the scope of this study, it could still provide a direction for further studies exploring the interaction between neighborhood greenness and park visitation.

Second, neighborhood greenness may have larger marginal effects on park visits of Black-majority groups. This finding is in line with previous studies, confirming that green spaces have a stronger moderation effect on health inequities, i.e., the low socioeconomic status groups could benefit more from green spaces (Frumkin et al., 2017; Mitchell & Popham, 2008). More neighborhood green spaces could attract people outdoors. Evidence has indicated that the presence of trees and grass in neighborhood common spaces could encourage people to engage in types of outdoor activities (Sullivan et al., 2004). In the time of the pandemic crisis, when many indoor recreation facilities closed, the large, open, and nearby home green spaces received particular attention and became desirable destinations for people to maintain recreation activities (fisher & Grima, 2020; Grzyb et al., 2021; Korpilo et al., 2021). However, the Black-majority neighborhoods tend to have a higher dependency on proximate green spaces, as the free and accessible attributes of green spaces make them one of the few choices for outdoor activities among ethnic minorities who cannot easily afford private recreation options. In contrast, the white population tends to have more alternative options, such as private gardens or other types of recreation facilities, to satisfy their recreational needs. Hence, green spaces have a better promotion effect on the Black-majority population than the other population.

5. Practical implications and study limitations

Although this study is primarily observational and not designed to evaluate specific interventions, the findings offer several practical implications for promoting racial equity in park access and usage. First, the persistence and amplification of racial disparities in park visitation underscore the urgency of targeted investments in green infrastructure, particularly in Black-majority neighborhoods. Enhancing park availability, improving facility quality, and ensuring perceived and actual safety are essential steps toward creating equitable outdoor environments.

Second, increasing neighborhood-level greenness—through strategies such as tree planting, community gardens, and pocket parks—may serve as cost-effective interventions to facilitate daily contact with nature. These measures can be especially impactful in communities where access to large parks is limited, offering a buffer against structural disparities in park distribution.

Third, planners and policymakers should adopt inclusive, community-driven approaches to park design and management. Actively involving Black residents and other underserved populations in the planning process can ensure that green spaces are culturally relevant, physically accessible, and aligned with local needs and preferences. For instance, programming that supports multigenerational use, facilitates safe social interaction, or reflects community identity may increase both the appeal and utilization of parks among marginalized groups.

Taken together, these strategies align with our findings by addressing structural and environmental barriers to equitable park usage. Future research could further explore the effectiveness of such interventions and investigate how public green space systems can better serve as inclusive urban infrastructure that supports health and well-being for all.

This study has several limitations. First, the analysis was conducted at the CBG level rather than individual levels, which may suffer from the "ecological fallacy" issue. The mobile-based data generally aggregates information for user privacy but could provide a large spatial scale and a long period of choice for analysis. However, the racial information and corresponding visitation data could not be obtained at the individual level. The survey data with specific sociodemographic information could potentially address such issues, but it is generally high-cost with a limited sample size. Second, though the policy stringency index has been included in our models, the closure of parks or facilities in them or indoor recreational facilities, which would prohibit or encourage park visitation directly (Curtis et al., 2022; Reid et al., 2022), were not taken into account. We did not find other suitable data resources that include such park information on a national scale. However, the level of policy stringency could partly control the impact of policy on park visit behavior to a certain extent. Third, weather conditions, which determine the feasibility of many park-based activities and thus park visitation decisions (Rice & Pan, 2021), are not considered in this study, even though the use of YOY observations might partly mitigate the seasonality factor.

Finally, it is important to acknowledge the limitations inherent in the use of mobile phone-based location data. The SafeGraph dataset used in this study represents approximately 10 % of anonymized mobile devices in the US, and not all individuals enable location services. Consequently, while the data provide broad coverage and high temporal resolution, they may not be fully representative of the general population—particularly among demographics less likely to carry smartphones or share location information. However, several recent studies have validated the reliability of the SafeGraph dataset by comparing it to official park visitation statistics at local or state levels, finding strong temporal correlations in visitation trends (e.g., Li et al., 2021; Kang et al., 2020). These validations support its utility in detecting temporal dynamics and spatial disparities in park usage. Given the nationwide scope and longitudinal nature of this study, consistent and standardized official park visitation records are largely unavailable for many regions. In this context, SafeGraph provides a practical and valid data source that enables large-scal, time-sensitive assessments of park visitation behaviors.

6. Conclusion

This comprehensive longitudinal study explored the long-term racial inequity of park visitation, including both the park visit counts and the number of visited parks in the US from the COVID-19 pandemic outbreak to the post-pandemic era in 2020 and 2021. Based on the results, we can conclude that the racial inequity of park usage has continuously widened along with the pandemic progress. The majority of Black-minority groups consistently outperformed the Black-majority groups in park access, and the disparity between them has widened. Nonetheless, neighborhood greenness could alleviate such disparity, that the Black-majority groups with higher greenness presented a lower disparity with the Black-minority groups. Overall, this study depicted a clear picture of racial inequity change in park visitation behavior and raised concerns.

CRediT authorship contribution statement

Xueying Wu: Writing – original draft, Software, Data curation, Visualization, Methodology, Conceptualization. **Yi Lu:** Supervision, Writing – review & editing, Funding acquisition. **Di Wei:** Software, Validation. **Wendy Y. Chen:** Supervision, Conceptualization, Methodology.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2025.101105.

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