Transit to parks: An environmental justice study of transit access to large parks in the U.S. West

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A B S T R A C T

Large parks—including regional parks, state parks, and national forests and parks—have particular health, social, and environmental benefits. Thus, promoting equal access to large parks is increasingly becoming a goal of environmental justice activists, planners, and policymakers. Disadvantaged populations (e.g., low-income people of color) have worse walking access to large parks than more privileged groups and might rely on public transportation to access such parks. But empirical studies on whether access to large parks via public transit is justly distributed are lacking. In this paper, we examine the relationship between a novel measure of public transit access to large parks (the T2P index) and neighborhood-level disadvantage (income, race/ethnicity, and age). Using network analysis with public transit feed data and park location data, we calculate the T2P index for every census block group in the 15 largest metropolitan statistical areas (MSAs) in the U.S. West. We find some evidence of environmental injustice. A spatial filtering model shows that T2P access increases when a neighborhood has a larger share of non-Hispanic Whites and a smaller share of older adults, but that median household income is not associated with T2P in the entire sample. We also find that some regions present significant environmental injustices in T2P whereas others have fewer to no injustices. Transit agencies and park planners could use our T2P index and findings to prioritize transit investment for disadvantaged populations and promote healthy living.

1. Introduction

Large parks, which include regional parks, state parks, and national forests and parks, have particularly strong benefits for human health and environmental sustainability. Those benefits include improved physical health outcomes (Brown et al., 2014; Jansen et al., 2017; Rundle et al., 2013; Sugiyama et al., 2010) and psychological well-being (Duvall and Kaplan, 2014; Korpela et al., 2014; Wood et al., 2017), the opportunity to host many recreational programs (Czerniak et al., 2007), and increased ecological diversity (Oliver et al., 2011; Fernández-Juricic, 2000). Thus, creating the conditions for equal access to parks is an important objective for healthy, just, and resilient cities. Low-income people, children, older adults, and people with disabilities are particularly dependent on having easy access to parks, as they might not have the means to afford private recreation settings and might have limited mobility options (Rigolon, 2017). Yet, low-income people in urban regions of the Global North and Global South tend to live farther from larger and higher-quality parks than more advantaged groups (Rigolon, 2016; Rigolon et al., 2018; Wolch et al., 2014). Such situations show that uneven walking access to large parks is an environmental justice issue.

Although disadvantaged populations often have limited access to personal vehicles and are more dependent on public transit to access daily activities, evidence suggests that they also often live further away from public transportation service (Karner, 2018; Welch and Mishra, 2013) “that provides general or special service to the public on a regular and continuing basis” such as buses, subways, rail, and trolleys (Federal Transit Administration, 2021). As a result, they might face an additional barrier to accessing large parks, and these issues have been recently been the target of “transit to parks” or “transit to trails” initiatives to connect urban residents to nature via transit (Los Angeles Metro, 2019; The
Specifically, we do not know whether, in addition to experiencing injustices in walking access to large parks (e.g., Rigolon, 2017; Wolch et al., 2015), disadvantaged groups also experience unjust transit access to such parks.

Therefore, in this study, we examine how accessibility to large parks via transit varies by neighborhood socio-demographic characteristics in the 15 largest metropolitan areas in the Western United States (henceforth, U.S. West). Results from spatial filtering models show a general pattern of environmental injustice in transit access to large parks—with consistent injustices for disadvantaged racial/ethnic and age-group—and regional variations of such injustices. By incorporating transit routes and schedule information into the network analysis, our novel accessibility metric could help planners, transit agencies, and decision-makers identify priority areas of transit investment to improve access to outdoor recreation opportunities for disadvantaged groups. Findings from this study can also help academics better understand environmental justice issues in multi-modal accessibility to large parks, advancing the growing international literature on “green justice” (see Kabisch and Haase, 2014; Kronenberg et al., 2020; Rutt and Gulbrandsen, 2016). Our work shows that inequalities in transit access to large parks are also an environmental injustice alongside inequalities in walking access to such parks.

2. Literature review

2.1. Transit accessibility: benefits, measurements, and environmental justice

Transit agencies are charged with the efficient provision of transit service such that it achieves two commonly accepted goals: 1) to provide a safe and convenient alternative to automobile travel for those who own personal vehicles and 2) to provide access to daily needs for individuals that do not have access to personal vehicles. Some have argued that it is the first of these goals that receives the vast majority of transit agencies’ attention (Greens, 2005; Karner, 2018; Karner et al., 2018; Wei et al., 2018). But a focus on this measure alone can lead transit agencies to neglect the second stated goal of transit service: providing access for riders without alternative transportation options (Lyons and Choi, 2021; Murray et al., 1998).

As “a measure of an individual’s freedom to participate in activities in the environment” (Weibull, 1976: 357), accessibility has been a critical goal in urban and transportation planning (Ferreira and Batey, 2007; Proffitt et al., 2019). In transportation research, accessibility can be defined as “the ease with which any land-use activity can be reached from a location using a particular transport system” (Dalvi and Martin, 1976: 17; Geurs and van Wee, 2004). Some scholars have proposed creating new performance measures of transit agencies that capture their ability to facilitate accessibility for disadvantaged populations. Early iterations of this effort were simple indices in which researchers analyzed the socioeconomic characteristics of neighborhoods and compared them to the level of transit service provided there (Foth et al., 2013; Mambo et al., 2013; Mananu and El-Geneidy, 2012). Techniques have since progressed, and scholars have incorporated a more nuanced approach to assessing justice in transit service, including using a multifaceted group of transit service measures (Welch and Mishra, 2013) and relying on emerging software capabilities to model transit schedule information (Karner, 2018; Lyons and Choi, 2021).

There is, however, some debate as to how well transit agencies have performed in their task of providing economic opportunity for disadvantaged populations. Welch and Mishra (2013) show an unequal distribution of transit service in Baltimore, MD, and a similar result was determined by Karner (2018) in Phoenix, AZ. Alternatively, Lyons and Choi (2021) find that by their measure, five out of six regions in their study demonstrated transit systems that provided better economic opportunity for disadvantaged populations. This debate indicates the emergent nature of transit justice measures and the need for further research on the topic.

Much of the framing around public transit accessibility and justice relates to upward mobility and economic opportunity (Golub and Martin, 2014; Martens et al., 2012; Neuwirth, 1990; Sanchez, 1999). Transit has been considered a tool for alleviating poverty, or at the very least, for moderating the effects of spatial mismatch on poverty (Lyons and Ewing, 2020; Sanchez et al., 2004). However, if we refer to the second stated goal of transit agencies, to provide access to the daily needs of transit-dependent populations, we see that economic opportunity satisfies only a part of that goal. Other needs that contribute to the quality of life, such as recreation, have received very little attention from transit scholars to date. This paper will utilize some of the advancements in measuring transit accessibility and apply them to another important consideration for disadvantaged populations: access to large parks.

2.2. Access to large parks: benefits, measurements, and environmental justice

Parks of any size play critical roles in creating sustainable regions, providing social, economic, and environmental benefits (Chiesura, 2004; Wolch et al., 2014). In particular, large parks have been given special attention due to the complexity and diversity in relation to programs, ecology, designing and planning processes, and surrounding urban fabrics (Czerniak et al., 2007). Public health studies emphasize the associations between living near large parks and physical and mental health outcomes, including lower BMI (Rundle et al., 2013), higher levels of physical activity (Brown et al., 2014; Jansen et al., 2017), more prolonged recreational walking (Sugiyama et al., 2010), and enhanced mental well-being (Wood et al., 2017). More exposure to nature-based recreation contributes to improving psychological and emotional well-being, such as reduced stress and nervousness and enhanced social connectedness and life outlook (Duvall and Kaplan, 2014; Korpela et al., 2014). Also, larger parks have a greater cooling effect than smaller ones (Bacci et al., 2003; Bowler et al., 2010; Chang et al., 2007), and park size is one of the main predictors of bird species richness (Fernández-Juricic, 2000; Oliver et al., 2011). Property and house premium increases with park acreage (Crompton and Nicholls, 2020; Poudyal et al., 2009).

The vast majority of literature on park accessibility to date has focused on walking access to parks (Rigolon, 2016), with the understanding that many urban residents walk to neighborhood parks (Derose et al., 2015; Loukaitou-Sideris and Stieglitz, 2002). But in the case of large parks, private vehicles and public transit are other common access modes (Downward and Lumsdon, 2004; Pettebone et al., 2011). Recently, a few studies have examined park accessibility using other modes of transportation, including transit (Chang et al., 2019; Dony et al., 2015; Liang and Zhang, 2018; Xu et al., 2017). Those studies measured transit accessibility to parks using the gravity model (Chang et al., 2019; Liang and Zhang, 2018), the floating catchment area (FCA) method (Dony et al., 2015), or only the travel time (Xu et al., 2017). The gravity model can be advantageous in measuring large park access as it captures both the attraction (often measured as park size or the number of facilities) and the distance friction in a more realistic, continuous scale.

Planning practitioners in the U.S. and elsewhere have also started to measure park access through transit, particularly focusing on large parks within or near a metropolitan area (Los Angeles Metro, 2019; The Wilderness Society, 2019). And the National Park Service (1999, 2018) in the U.S. has been studying alternative transportation options for its visitors to reduce traffic congestions and emissions while improving visitor experiences. Other cities around the world are increasingly providing transit access to large parks, including in South Africa (Table Mountain Aerial Cableway, 2021), Australia (Hendrigan and Wilderness Society, 2019).

Some studies have examined accessibility to any park via public transit (see Chang et al., 2019; Dony et al., 2015; Liang and Zhang, 2018), but empirical evidence on transit access to large parks is limited. Specifically, we do not know whether, in addition to experiencing injustices in walking access to large parks (e.g., Rigolon, 2017; Wolch et al., 2005), disadvantaged groups also experience unjust transit access to such parks.

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Newman, 2013), and Europe, where several mountain parks and trails can be reached via train (EURAC Research, 2013). This suggests that transit might be a viable transportation mode to reach larger parks where park users spend considerable amounts of time (e.g., hike, picnic, camping, hunting/fishing), especially for people with limited access to personal vehicles (e.g., low income, children, the elderly).

A growing body of literature has examined which demographic groups have better access to parks through the lens of environmental justice (Boone et al., 2009; Byrne et al., 2009; Nesbitt et al., 2019; Pincetl, 2003; Rigolon, 2016, 2017; Sister et al., 2010; Wang and Qiu, 2018; Wolch et al., 2005, 2014; Zhou and Kim, 2013). Previous studies show that low-income people and Black, Indigenous, and People of Color (BIPOC) communities have worse access to parks, and particularly to large parks, in cities around the world (see Rigolon, 2016). These inequalities have been considered as environmental justice issues, as these publicly-funded open spaces can promote human health and well-being (Boone et al., 2009).

Although this body of research on park accessibility and environmental justice is growing, a few areas remain understudied. First, as noted earlier, most studies examined walking accessibility to parks, and significantly fewer studies analyzed access to parks through other modes of transportation—in particular, transit, a viable mode for lower-income people. Second, most research studied accessibility to neighborhood parks, with limited work focusing on access to large parks, which people tend to visit more and spend a longer amount of time (Cohen et al., 2010; National Park Service, 2019; Zhang and Zhou, 2018). Lastly, most previous studies explore a single region, limiting the generalizability of their findings. Thus, it is still unclear whether transit accessibility to large parks and open spaces is equitable across socio-economic and racial/ethnic groups and across regions.

Based on the literature review, we ask two research questions aimed to fill the above gaps: How does accessibility to large parks via transit vary by neighborhood socio-demographic characteristics in the U.S. West? Which disadvantaged groups (e.g., BIPOC, low-income, young, and elderly people) experience injustices regarding transit-to-parks access in those regions? We hypothesize that transit access to parks is higher in privileged neighborhoods than in disadvantaged neighborhoods. In other words, we expect that disadvantaged neighborhoods—racial/ethnically, economically, or in terms of age group compositions—have poorer transit accessibility to large parks, which would worsen documented environmental injustices in walking access to those parks (see Rigolon, 2017; Wolch et al., 2005).

![Fig. 1. Map of 15 MSAs and large parks included in this study (note: the map shows only parks intersecting with MSA boundaries).](image-url)
3. Study site: the U.S. West

This transit-to-parks study focuses on major metropolitan areas in the U.S. West. According to the U.S. Census Bureau, the U.S. West consists of three Pacific states (California, Oregon, and Washington) and eight Mountain states (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming). Within the U.S. West, we selected the 15 largest metropolitan statistical areas (MSAs) in terms of population (see Fig. 1 and Table 1). We consider MSAs as an appropriate spatial extent to study because we aim to examine geographic and demographic variations in large park access within a region, and our findings could provide direct implications for regional planning agencies and transit authorities. Table 1 shows an overview of the 15 MSAs. These regions have notable variations in total population (highest in Los Angeles, lowest in Albuquerque), median household income (highest in San Jose, lowest in Tucson), and percentage of non-Hispanic White residents (highest in Portland, lowest in Fresno).

We focus on the U.S. West for several reasons. First, compared with other parts of the U.S., the U.S. West contains large amounts of public lands, including national parks and forests and state parks close to urban areas, and the federal government manages almost half of the land in this region (Rasker et al., 2013). Second, proximity to nature and the availability of outdoor recreation opportunities are attracting residents and companies to cities and towns in the U.S. West; thus, large parks are an economic development engine for the West (Rasker et al., 2013; Walls and companies). Third, increased recreational use of public lands by residents and tourists alike resulted in overcrowding and negative impacts on park infrastructure and their ecosystems, leading to claims that parks are “loved to death” (National Park Service, 2018b; Simmonds et al., 2018). Despite these negative outcomes, increased visitation of large parks signals heightened interest for those places in the U.S. West. And finally, a few studies documented environmental injustices in walking access to large parks in some of the U.S. West’s regions such as Los Angeles (Sister et al., 2010; Wolch et al., 2005) and Denver (Rigolon, 2017). Our analysis of walking access to large parks in the 15 sampled MSAs confirms that environmental justice issues exist. Indeed, independent-sample t-tests show that census block groups whose centroids are within ½-mile from a large park (larger than 20 acres) are wealthier and have more non-Hispanic White residents than those located further away (Table 2).

Although the U.S. West is relatively unique in that it has an abundance of large parks, its urban regions also have many common traits to other U.S. metropolitan areas and other Global North countries. Such common traits include environmental justice issues in access to parks (see Rigolon, 2016), growing population and tourism putting pressure on public lands, including national parks and forests and state parks close to urban areas, and the federal government manages almost half of the land in this region (Rasker et al., 2013). Second, proximity to nature and the availability of outdoor recreation opportunities are attracting residents and companies to cities and towns in the U.S. West; thus, large parks are an economic development engine for the West (Rasker et al., 2013; Walls and companies). Third, increased recreational use of public lands by residents and tourists alike resulted in overcrowding and negative impacts on park infrastructure and their ecosystems, leading to claims that parks are “loved to death” (National Park Service, 2018b; Simmonds et al., 2018). Despite these negative outcomes, increased visitation of large parks signals heightened interest for those places in the U.S. West. And finally, a few studies documented environmental injustices in walking access to large parks in some of the U.S. West’s regions such as Los Angeles (Sister et al., 2010; Wolch et al., 2005) and Denver (Rigolon, 2017). Our analysis of walking access to large parks in the 15 sampled MSAs confirms that environmental justice issues exist. Indeed, independent-sample t-tests show that census block groups whose centroids are within ½-mile from a large park (larger than 20 acres) are wealthier and have more non-Hispanic White residents than those located further away (Table 2).

Table 1
The 15 largest MSAs in the U.S. West (note: demographic attributes were aggregated from block-group-level estimates).

<table>
<thead>
<tr>
<th>Region</th>
<th>Population</th>
<th>Land area (sq. mi.)</th>
<th>Median household income</th>
<th>Non-Hispanic White (%)</th>
<th>Number of large parks (&gt;20 acres)</th>
<th>Number of transit operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque, NM</td>
<td>905,049</td>
<td>9,296</td>
<td>$54,198</td>
<td>42.2</td>
<td>58</td>
<td>1</td>
</tr>
<tr>
<td>Denver-Aurora-Lakewood, CO</td>
<td>2,796,753</td>
<td>8,403</td>
<td>$78,824</td>
<td>65.9</td>
<td>440</td>
<td>3</td>
</tr>
<tr>
<td>Fresno, CA</td>
<td>971,316</td>
<td>6,011</td>
<td>$51,862</td>
<td>31.6</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>Las Vegas-Henderson-Paradise, NV</td>
<td>2,112,436</td>
<td>8,061</td>
<td>$58,762</td>
<td>44.9</td>
<td>74</td>
<td>1</td>
</tr>
<tr>
<td>Los Angeles-Long Beach-Anaheim, CA</td>
<td>13,256,578</td>
<td>5,699</td>
<td>$74,786</td>
<td>32.2</td>
<td>684</td>
<td>21</td>
</tr>
<tr>
<td>Phoenix-Mesa-Chandler, AZ</td>
<td>4,561,038</td>
<td>14,600</td>
<td>$64,326</td>
<td>58.6</td>
<td>241</td>
<td>1</td>
</tr>
<tr>
<td>Portland-Vancouver-Hillsboro, OR-WA</td>
<td>2,382,037</td>
<td>6,824</td>
<td>$71,571</td>
<td>75.9</td>
<td>249</td>
<td>16</td>
</tr>
<tr>
<td>Riverside-San Bernardino-Ontario, CA</td>
<td>4,475,265</td>
<td>27,408</td>
<td>$62,899</td>
<td>36.0</td>
<td>197</td>
<td>7</td>
</tr>
<tr>
<td>Sacramento-Roseville-Folsom, CA</td>
<td>2,268,005</td>
<td>5,307</td>
<td>$69,789</td>
<td>56.3</td>
<td>166</td>
<td>7</td>
</tr>
<tr>
<td>Salt Lake City, UT</td>
<td>1,170,057</td>
<td>8,092</td>
<td>$72,705</td>
<td>73.5</td>
<td>77</td>
<td>1</td>
</tr>
<tr>
<td>San Diego-Chula Vista-Carlsbad, CA</td>
<td>3,283,665</td>
<td>4,526</td>
<td>$77,125</td>
<td>49.1</td>
<td>252</td>
<td>2</td>
</tr>
<tr>
<td>San Francisco-Oakland-Berkeley, CA</td>
<td>4,641,812</td>
<td>3,426</td>
<td>$103,124</td>
<td>42.8</td>
<td>322</td>
<td>17</td>
</tr>
<tr>
<td>San Jose-Sunnyvale-Santa Clara, CA</td>
<td>1,969,893</td>
<td>2,695</td>
<td>$116,590</td>
<td>35.7</td>
<td>112</td>
<td>3</td>
</tr>
<tr>
<td>Seattle-Tacoma-Bellevue, WA</td>
<td>3,735,216</td>
<td>6,309</td>
<td>$85,176</td>
<td>66.6</td>
<td>476</td>
<td>8</td>
</tr>
<tr>
<td>Tucson, AZ</td>
<td>974,564</td>
<td>9,191</td>
<td>$50,523</td>
<td>53.5</td>
<td>114</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>49,503,704</td>
<td>125,848</td>
<td>–</td>
<td>–</td>
<td>3,489</td>
<td>92</td>
</tr>
</tbody>
</table>

Table 2
&t-test results comparing environmental justice variables of block groups with and without access to large parks within ½-mile from a block group centroid.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Block groups with access to large parks</th>
<th>Block groups with no access to large parks</th>
<th>t-statistic (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median household income</td>
<td>$82,039</td>
<td>$70,656</td>
<td>-21.8 (&lt;.001)</td>
</tr>
<tr>
<td>Non-Hispanic White percent</td>
<td>52.1 %</td>
<td>44.7 %</td>
<td>-21.3 (&lt;.001)</td>
</tr>
</tbody>
</table>
on parks and public lands (see McClanahan, 2019), and the use of outdoor recreation to promote economic growth (see Bell et al., 2007). Thus, we believe that the findings of this study can be extended to other regions in the U.S. and globally.

4. Data and methods

4.1. Development of a “transit-to-parks” (T2P) index

Our transit-to-parks (T2P) index measures how many large parks residents can reach by using public transit and walking within a given time. For large parks, we include all public lands that are 1) owned and managed by federal, state, and local governments, 2) locate within or intersect with the MSA boundary, and 3) larger than 20 acres, a commonly-used upper-bound size limit of neighborhood parks (Cohen et al., 2016; Gupta et al., 2016; Mertes and Hall, 1996). For the time limit, we use 60 min of total travel time, including walking and transit rides. According to the 2017 National Household Travel Survey (Federal Highway Administration, 2018), average transit travel time for recreational activities was 63.2 min, and that for exercise was 45.0 min. Thus, we use 60 min as a one-way travel-time threshold. Applying the temporal limit was also needed for a practical reason as we had calculated transit travel time between every pair of Census block groups and large parks in the 15 selected regions.

We use a gravity model to measure T2P access.

$$\text{T2P}_{ij} = \sum_{J=1}^{N} C_i d_{ij}^\beta$$

where $T2P_{ij}$ indicates the Census block group $i$’s park accessibility; $C_i$ is the capacity of the park $j$ measured as the park’s size; and $d_{ij}$ is the transit travel time between the centroid of the block group $i$ and the entrance point of the park $j$. With a large park having multiple entrances, minimum travel time is chosen (see the next section for methods). $\beta$ is the travel friction coefficient and is tested at two different values—“1” and “2”, where 1 indicates that friction is a simple linear function of distance, and 2 indicates that friction increases as the square of the distance. Higher coefficients are often used to incorporate other costs relative to travel (e.g., time loss), making distance parks relatively less attractive. We compared models based on the two coefficients, and finally selected a value of 1, as this resulted in higher log-likelihood values and lower AIC values.

4.2. Data collection and processing

T2P index includes three parts: census block groups (travel origins), parks (travel destinations), and transit travel times. First, we use Census block groups as the unit of analysis in this study, given their fine scale (average of 1.56 square miles in our sample) and socio-demographic information provided from Census data. We downloaded the population-weighted centroid locations for block groups from the U.S. Census Bureau (2010). Point data, not a polygon, is essential in calculating travel times and creating service areas in network analysis.

Second, we extracted park locations as travel destinations from ParkServe® data (The Trust for Public Land, 2019), which includes comprehensive geographic information for park boundaries, types, and sizes. We included parks that had no restriction on public access and that were larger than 20 acres (8.09 ha). Because park entrance location data are not available at such a regional scale, we estimate them as any points where a park and roads intersect with each other. For road data, we used all roads from TIGER/Line® shapefiles (US Census Bureau, Geography Division, 2019) and excluded highways with limited access to adjacent lands. For park boundaries, we apply a 100-ft (30.5-meter) buffer since the road centerline may not touch a park boundary even when they are close enough, and there might be a pedestrian route between the two, not included in the TIGER/Line® shapefiles.

Last, to calculate transit travel times between parks and census block groups, we model a transportation network from two sources: road centerline data from TIGER/Line® shapefiles and transit service feed data (e.g., routes, stops, schedule) from General Transit Feed Specification (GTFS; OpenMobilityData, 2020). We first created a network dataset using the “GTFS to Network Dataset Transit Sources” tool in ArcGIS Pro and then built a service area of 60-minute transit travel time from each Census block group centroid in 15 regions. To capture recreational visits to parks, we calculated travel time on Saturday afternoon (4 pm), when such recreational activities might be more likely to happen (Banda et al., 2014; Shores and West, 2010). We then used the output service areas to identify accessible large parks from each Census block group. The next step was to calculate actual travel time between each block group and each park (within the 60-minute buffer) using the “OD Cost Matrix” ArcGIS tool.

We first calculated the T2P index for each pair of a block group and a park as park size (in square miles) divided by travel time (in minutes). Then, we aggregated individual T2P index values the Census block group level (i.e., for all accessible parks from each block group). Because the input data such as road network is limited within each MSA boundary, T2P values for block groups at the periphery of the MSA may be underestimated. Thus, we excluded block groups touching the MSA boundary, mostly rural or mountainous areas. The resulting dataset consists of 28,412 block groups. In addition to the T2P index, we also calculated walking access to parks (W2P) to control for the impact of physical proximity to large parks in modeling the transit access. Walking access to large parks is a dummy variable representing a block group having any large park within a quarter mile—10-minute walking distance—from its centroid (1 = access, 0 = no access).

For neighborhood characteristics, we measured six variables: 1) population density (number of people/sq.mi.), 2) job density (number of jobs/sq.mi.), 3) % of the non-Hispanic White population, 4) % of people under 18 years old, 5) % of people over 65 years old, and 6) median household income. We collected most sociodemographic data from the American Community Survey (ACS) 2013–2017 5-year estimates (Manson et al., 2019), whereas we gathered employment from the Longitudinal Employer-Household Dynamics (LEHD) data (U.S. Census Bureau, 2019). We excluded block groups with missing population or income data from the sample. To examine the effect of transit service on T2P index, we also incorporated three transit variables: 1) transit stop density of a block group, measured as the number of stops per square mile, 2) the total number of transit arrivals/departures at all stops within a block group on Saturday, and 3) a rail dummy variable (1 for any rail transit stop within a block group; 0 for otherwise). These variables represent transit coverage, frequency, and type, respectively. The data source was GTFS (OpenMobilityData, 2020).

Table 3 shows descriptive statistics of our independent variables. An average block group in those 15 regions has 47 % of non-Hispanic White population, which is lower than the national average (61.5 % in ACS
2013–2017). Median household income is $68,281, higher than the U.S. average ($57,652 in ACS 2013–2017). Age group distribution is similar to the national average (22.9 % under 18 years and 14.9 % over 65 years in ACS 2013–2017).

### 4.3. Data analysis

We expected that the T2P index depends on the physical and socio-demographic environments of a neighborhood. Also, the level of transit service (e.g., coverage, frequency, type) might be correlated with T2P access. Thus, we model T2P as a function of transit service variables and neighborhood environment variables. We used a multilevel model to represent the nested structure of the dataset, with multiple block groups (level 1) nested within a region (level 2).

\[
T2P_{ij} = \beta_0 + \beta_1 \text{Population density} + \beta_2 \text{Job density} + \beta_3 \text{Median household income} + \beta_4 \text{Job density} + \varepsilon_{ij}
\]

where \( T2P_{ij} \) indicates the T2P index at census block group \( i \) in region \( j \), \( r \) indicates the level-2 intercept for each covariate, \( \beta_0 \) and \( \varepsilon_{ij} \) show a coefficient and a variable related to walking access to parks, respectively, and \( \beta_2, \beta_3 \) and \( \text{Job density} \) show a set of coefficients and variables related to transit service, respectively (see Table 3 for the three variables). And \( \beta_1, \text{Population density} \) and \( \text{Job density} \) show a set of coefficients and variables related to neighborhood physical and socio-demographic characteristics, respectively (see Table 3 for the six variables). \( u_{ij} \) represents the level-2 residual for each covariate and \( \varepsilon_{ij} \) indicates the level-1 residual.

We built a preliminary multi-level model following the specification above, then tested for spatial autocorrelation in the level 1 residuals using Moran’s I. The results were highly significant (\( I = 0.78, p = <.001 \)), indicating a lack of independence in the residuals. This spatial dependence likely arises as the outcome variable is a distance value, which presents as a spatially smooth field.

We used eigenvector spatial filtering (ESF) to account for the spatial autocorrelation, which imposes a filter \((I - \rho W)\) to remove autocorrelation in the error term of a model (Griffith, 2003):

\[
y = \beta X + \varepsilon (I - \rho W)^{-1}
\]

where \( I \) is the identity matrix, \( W \) is a spatial weight matrix and \( \rho \) is a coefficient representing the level of spatial dependency. Practically, the filter is estimated by first carrying out an eigendecomposition of a modified version of the weight matrix into a set of \( n \) orthogonal Moran Eigenvectors (ME):

\[
ME = (I - 11^T/n) \times W \times (I - 11^T/n)
\]

A subset of these eigenvectors is then selected for inclusion in the model by a stepwise procedure, where at each iteration the eigenvector that reduces Moran’s I the most when included in the model is chosen (Dormann, 2007). The stepwise procedure stops when the \( p \)-value of Moran’s I has been increased above some threshold (here, \( p > .05 \)).

Murakami and Griffith (2015) proposed an extension to the ESF model in which the set of eigenvectors are considered as a random effect (RE-ESF). This allows the ESF approach to be incorporated in a multi-level model by filtering the group level residuals, i.e., addressing any remaining spatial autocorrelation between groups (Hu et al., 2019). We use this method to model the full dataset for all 15 regions, using the `spmoran` package in R 3.6.3 (Murakami, 2019; R Core Team, 2020). One of the challenges in the ESF model is the calculation of the MEs when \( n \) is large. For our full model, \( n = 28,412 \), and we used the fast approximation method of Murakami and Griffith (2018).

The RE-ESF model substantially reduced the spatial autocorrelation, but did not eliminate it (\( I = 0.11, p = <.001 \)), due in part to the non-contiguous nature of the data, and the very different patterns of travel times in each region. We therefore estimated individual ESF models for each region, using the ME function (Moran’s eigenvector extraction) in the `spatialreg` package (Bivand et al., 2013). The resulting Moran’s I values from the spatial filtering models range from 0.01 to 0.03, and are all non significant (\( p > .05 \)), indicating no spatial autocorrelation.

### 5. Results

#### 5.1. Descriptive statistics of T2P index

For each neighborhood, the T2P index measures total acreage of large parks (sq.mi.) accessible within 60 min by public transit, inversely weighted by travel time (in minute) for each park. The unit of the T2P index is acre/minute. For example, when a block group has only one 40-acre park which can be reached in 20 min by transit, the T2P value is 2 acre/minute (40 divided by 20). With two 20-acre parks both accessible in 20 min, the T2P is also 2 acre/minute (20/20 plus 20/20). Fig. 2 shows an example map of T2P index in Denver region.

The T2P index in the 15 U.S. West regions ranges from 0.01 acre/minute (Fresno) to 18.6 (Salt Lake City), showing a large variation across regions (Table 4). The highest within-region variation is found in the Los Angeles region, followed by Riverside and Sacramento.

An average number of large parks accessible in 60 min from a block group ranges from 1.6 (Fresno) to 12.6 (Los Angeles) with an average of 7.9 parks. In terms of area, an average block group has access to 49,194 acres (76.9 square miles) of large parks via public transit, ranging from 184 (Fresno) to 448,527 acres (Salt Lake City). Regarding walking access...
Fig. 2. T2P index map in Denver region.
Table 4
Descriptive statistics of T2P index and large park access by region.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of block groups</th>
<th>Parks via transit (count): mean</th>
<th>Parks via transit (acre): mean</th>
<th>T2P: mean (std. dev.)</th>
<th>W2P: mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque, NM</td>
<td>531</td>
<td>4.05</td>
<td>2,425</td>
<td>0.14</td>
<td>0.33</td>
</tr>
<tr>
<td>Denver-Aurora-Lakewood, CO</td>
<td>1,720</td>
<td>10.36</td>
<td>14,475</td>
<td>0.92</td>
<td>0.52</td>
</tr>
<tr>
<td>Fresno, CA</td>
<td>498</td>
<td>1.58</td>
<td>184</td>
<td>0.01</td>
<td>0.09</td>
</tr>
<tr>
<td>Las Vegas-Henderson-Paradise, NV</td>
<td>1,233</td>
<td>6.92</td>
<td>15,027</td>
<td>0.37</td>
<td>0.21</td>
</tr>
<tr>
<td>Los Angeles-Long Beach-Anaheim, CA</td>
<td>7,955</td>
<td>12.61</td>
<td>65,060</td>
<td>4.55</td>
<td>0.26</td>
</tr>
<tr>
<td>Phoenix-Mesa-Chandler, AZ</td>
<td>2,632</td>
<td>4.76</td>
<td>45,459</td>
<td>2.61</td>
<td>0.32</td>
</tr>
<tr>
<td>Portland-Vancouver-Hillsboro, OR-WA</td>
<td>1,351</td>
<td>6.14</td>
<td>13,750</td>
<td>0.46</td>
<td>0.30</td>
</tr>
<tr>
<td>Riverside-San Bernardino-Ontario, CA</td>
<td>1,990</td>
<td>4.70</td>
<td>129,182</td>
<td>9.15</td>
<td>0.20</td>
</tr>
<tr>
<td>Sacramento-Roseville-Folsom, CA</td>
<td>1,276</td>
<td>4.63</td>
<td>22,197</td>
<td>5.65</td>
<td>0.41</td>
</tr>
<tr>
<td>Salt Lake City, UT</td>
<td>617</td>
<td>5.28</td>
<td>448,527</td>
<td>18.61</td>
<td>0.31</td>
</tr>
<tr>
<td>San Diego-Chula Vista-Carlsbad, CA</td>
<td>1,750</td>
<td>5.62</td>
<td>7,082</td>
<td>0.87</td>
<td>0.47</td>
</tr>
<tr>
<td>Sacramento-Oakland-Berkeley, CA</td>
<td>2,784</td>
<td>6.79</td>
<td>9,217</td>
<td>0.67</td>
<td>0.40</td>
</tr>
<tr>
<td>San Jose-Sunnyvale-Santa Clara, CA</td>
<td>1,068</td>
<td>5.38</td>
<td>1,960</td>
<td>0.11</td>
<td>0.31</td>
</tr>
<tr>
<td>Seattle-Tacoma-Bellevue, WA</td>
<td>2,411</td>
<td>6.63</td>
<td>5,319</td>
<td>0.20</td>
<td>0.39</td>
</tr>
<tr>
<td>Tucson, AZ</td>
<td>596</td>
<td>5.88</td>
<td>135,750</td>
<td>4.11</td>
<td>0.40</td>
</tr>
<tr>
<td>Total</td>
<td>28,412</td>
<td>7.85</td>
<td>49,194</td>
<td>3.14</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Table 5
Spatial filtering model of T2P index with random effects for 15 regions (note: dependent variable is a log-transformed T2P index).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-3.300</td>
<td>0.163</td>
<td>-20.200</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Walking access to large parks</td>
<td>0.890</td>
<td>0.022</td>
<td>40.202</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Population density</td>
<td>0.005</td>
<td>0.002</td>
<td>3.120</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Job density</td>
<td>0.001</td>
<td>0.001</td>
<td>0.756</td>
<td>0.45</td>
</tr>
<tr>
<td>% non-Hispanic White</td>
<td>0.003</td>
<td>0.001</td>
<td>4.393</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>% under 18</td>
<td>0.000</td>
<td>0.002</td>
<td>-0.314</td>
<td>0.75</td>
</tr>
<tr>
<td>% over 65</td>
<td>-0.006</td>
<td>0.001</td>
<td>-5.056</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Median household income</td>
<td>0.000</td>
<td>0.009</td>
<td>0.246</td>
<td>0.81</td>
</tr>
<tr>
<td>Transit density</td>
<td>0.070</td>
<td>0.012</td>
<td>5.721</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Transit frequency (log-transformed)</td>
<td>0.017</td>
<td>0.003</td>
<td>5.117</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Transit type (rail)</td>
<td>0.065</td>
<td>0.051</td>
<td>1.271</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Model diagnostics
Pseudo R²: 0.56 Log-likelihood: -54,646.68 AIC: 109,523.40 BIC: 109,447.20

neighborhood is not significantly associated with the T2P index, and neither was the percentage of people under 18.

Among transit-related variables, higher values of transit stop density and transit frequency are associated with higher T2P index values. This conforms with our hypothesis about the relationship between transit coverage and frequency and the T2P index. Having a rail transit station in a neighborhood shows no association with the T2P index. This finding follows with the theory that rail transit service typically serves parts of a region with higher employment and residential densities—places where we would not expect to find large parks (Dill et al., 2013).

To test the results’ sensitivity to travel friction choices, we also ran a separate model with a travel friction coefficient of 2 in calculating the T2P index, which puts more weight on the parks located closer to each neighborhood. Statistically significant explanatory variables (p < .05) in our main model remain significant in this sensitivity analysis model, except for two variables: population density is no longer significant (p = .12), and rail dummy becomes significant (p < .05). The model diagnostics for the sensitivity analysis model (Pseudo R²: 0.55; Log-likelihood: -58,494) were comparable to those of our main model presented in Table 5. Thus, we conclude that our findings are not sensitive to variations in the travel friction choice.

Due to the remaining spatial autocorrelation in the full model, and to examine MSA-level variations in what predicts the T2P index, we also ran a spatial filtering model for each MSA with the same set of independent variables (see Tables 6 and 7). Six regions—Fresno, Phoenix, Riverside, Sacramento, Salt Lake City, and San Francisco MSAs—show racial/ethnic injustice in T2P. In other words, neighborhoods with larger shares of racial/ethnic minority people tend to have poorer access to large parks via transit in those regions, when other factors are equal. Also, four regions—Albuquerque, Fresno, Salt Lake City, and Seattle—indicate income-based injustice in T2P access, as low-income neighborhoods have lower access to large parks via transit than wealthier neighborhoods. Lastly, in some regions, neighborhoods with more children (in Salt Lake City and San Diego) or more elderly people (in Las Vegas, Phoenix, Portland, Salt Lake City, and San Jose) showed significantly less T2P access. Notably, Salt Lake City shows injustices for all four demographic categories. Likely, the relatively large number of MSAs experiencing racial/ethnic injustice (7 MSAs) and age-related injustice for the elderly (5 MSAs) contribute to these same results in the entire sample (Table 5).

Three regions—Denver, Los Angeles, and Tucson—do not show any indication of racial/ethnic, income, or age-related injustice in T2P access. Contrary to those regions experiencing racial/ethnic injustice, neighborhoods with smaller percentages of non-Hispanic White people have better transit-to-parks access in Denver, Los Angeles, San Diego, and Seattle, when other factors are equal. In Denver, Los Angeles, and Las Vegas, lower income block groups have higher T2P values.

5.2. Regression results

Table 5 shows the results of a multilevel spatial filtering model to predict variations in the T2P index across the 15 MSAs. The results highlight socio-demographic inequality in T2P distribution. As expected, the T2P index is higher in proximity to large parks (i.e., block groups with walking access to those parks) and in areas with higher population density. But the T2P index is not associated with job density, implying that employment clusters may not have better access to large parks, at least on weekends (note that our T2P index is computed for transit access on Saturday at 4 pm). Among our environmental justice variables of interest, we find that, as expected, the T2P index increases with the percentage of non-Hispanic White residents. As we also hypothesized, the percentage of older adults is negatively associated with the T2P index. Unexpectedly, median household income of a
to large parks, about one-third of block groups in the 15 regions are within 10-minute walking distance from a large park, ranging from 9% in Fresno to 52% in Denver. The average T2P index differs between block groups having walking access (5.9 on average) and those without access (1.8 on average), and a t-test confirms that there is a statistically significant difference (p < .01), supporting the inclusion of the W2P variable in our models.
considered age (see Rigolon, 2017 for an exception), our findings expand the range of demographic characteristics for which injustices in access to parks have been considered.

Interestingly, we find that a neighborhood’s median household income is not associated with the T2P index in the main model using the entire sample. In other words, the entire sample does not show environmental injustices in transit access to large parks based on income (although some regions show these injustices; see below). This finding is in line with work by Lyons and Choi (2021), who found that transit access to jobs, when measured comprehensively, is better for disadvantaged populations than advantaged populations in five of the six U.S. regions they studied. They posit that transit agencies have focused service resources on disadvantaged areas in compliance with Title VI regulations and in an attempt to bolster ridership (Lyons and Choi, 2021). Service that favors economic access for disadvantaged neighborhoods might also favor park access, at least in terms of transit system access at the origin. However, we report income-based injustices for walking access to large parks (see Table 2). Taken together, these findings suggest that transit might help attenuate existing income-based injustices in walking access to parks by providing affordable transportation options to reach large parks from park-poor, low-income neighborhoods.

Regional models show variations in the demographic groups experiencing injustice in T2P access. Racial/ethnic injustice in T2P access was found in seven regions, income injustice in four regions, and age-group injustice in six regions. Regions with income-based injustices tend to have fewer large parks and lower T2P values on average. The scarcity of large parks may contribute to the unequal distribution of different income groups within a region, with wealthier groups being able to afford the more limited housing options near large parks, which carry a significant real estate premium (Crompton and Nicholls, 2020). Those regions are also among those showing the most substantial gap in median household income between block groups within walking distance of large parks (½-mile) and their counterparts. Most of the regions with racial/ethnic injustice in the T2P index have large Hispanic populations (data not shown), confirming findings from other studies showing that Hispanic people experience inequalities in access to parks (see Wolch et al., 2005). The injustice in the T2P index affecting older people is found in regions with low levels of walking access to large parks. These regions may have some large parks on the periphery of the region (e.g., Tonto National Forest in Phoenix, Mt. Hood National Forest in Portland), but not enough large parks within their urban cores. Planners in these regions may need to provide better transit-to-park routes and schedules for neighborhoods with high shares of older adults.

The race/ethnic-based injustices in T2P access that we found in the
15 U.S. West regions reflect environmental injustice issues identified in the growing international literature on park accessibility. Many studies in cities of the Global North and Global South have shown measurable injustices in walking access to neighborhood parks (Rigolon, 2016; Rigolon et al., 2018; Wolch et al., 2014). Transportation studies also found an unequal distribution of transit services in urban areas (Welch and Mishra, 2013; Karner, 2018). Building on those bodies of literature, this study sheds light on the unique opportunity to connect park-poor, disadvantaged neighborhoods to large parks via transit. Given the enhanced benefits of large parks and the affordability of public transit services, the new T2P index and our research findings add new insights to the environmental justice literature on green space management and transportation planning.

6.2. Study limitations

This study has a few limitations. First, as block groups may contain highly heterogeneous individuals, the modifiable areal unit problem may exist in our demographic data, and the results based on aggregated data cannot be interpreted as inferences about individual residents. Future research on similar topics might utilize individual-level data, such as mobile phone tracking data or travel surveys. Second, due to limitations in data availability, we approximated park entrances as the intersecting points between road networks and park boundaries. If park entrance data were to become available, a more accurate T2P index can be computed. Third, transit access to large parks may be experienced differently based on the region and personal attributes. Although we used a 60-minute threshold, the maximum time that people are willing to travel to large parks might vary by region; that time might be shorter for regions with lots of large parks nearby (e.g., Salt Lake City) and longer for regions with fewer large parks. Also, while we used Saturday 4 pm as a peak time of large park visitation based on the literature (Banda et al., 2014; Shores and West, 2010), some groups such as older adults or families with young children may visit it during the week or on other times of the day. Future research could integrate surveys of large park users to understand local averages of acceptable travel times and different visitation patterns. Finally, large parks are not created equal; they may significantly differ in types (e.g., developed regional parks versus wild national forests), quality, amenities, recreation programs, safety, and perceptions of residents. Future research could model some of these large park characteristics alongside accessibility via transit.

6.3. Planning implications

The findings of this study suggest several ways in which park agencies and transit agencies can plan for more environmentally just access to large parks. First, the T2P tool we developed can be used in other geographic contexts having transit feed data and park location data. Applying the T2P index to other contexts might help transit agencies understand how to adapt their system to ensure that their service provides convenient access to large parks or other public amenities (e.g., libraries, community centers).

Second, our findings show that in the sample of 15 MSAs, transit access to large park is not higher in wealthier neighborhoods than in poorer ones, whereas we also find that walking access to large parks is indeed better in more affluent areas. These findings point to the fact that transit agencies, deliberately or not, might help to connect lower-income people to large parks. Thus, we suggest that following examples in Los Angeles and Seattle, transit agencies should intentionally partner with park agencies to ensure that transit becomes a tool to address income-based environmental injustices in access to large parks (Los Angeles Metro, 2019; The Wilderness Society, 2019). Examples from South Africa (Table Mountain Aerial Cableway, 2021), Australia (Hendrigan and Newman, 2013), Europe (EURAC Research, 2013), and the San Francisco Bay Area in the U.S. (East Bay Regional Park District, 2021) also demonstrate best practices.

Third, our finding that race/ethnic-based injustices exist even in transit access to large parks suggests that planning efforts by parks and transit agencies alike should consider the legacies of institutional racism. These planning efforts should be particularly deliberate in countries such as the United States and South Africa, where access to parks and race are intertwined due to their history of segregation and racial injustice (Byrne et al., 2009; Donaldson et al., 2016). The use of public transportation as a tool to achieve environmental justice may be even more crucial in European and Asian cities where public transit systems have been more fully developed (Sinha, 2003).

Planning transit for park access provides a unique challenge for transit service planners. Typical variables that they consider when planning transit service include residential and employment densities, as investment in service generally results in higher ridership in areas with higher densities than in less dense areas (Dill et al., 2013; Karner, 2018). These densities do not often exist, however, at or near large parks. If transit agencies are considering planning service in an environmentally just way, park access for disadvantaged populations should also be included.

Our models show that T2P is associated with both transit service density and frequency, variables that work in different ways. Higher transit service frequency allows for shorter wait times at the origin or at transfers between routes, making transit connections to parks more viable at the 60-minute threshold. Higher transit service density can also help connect disadvantaged populations to parks by reducing walking distances and times to routes that will ultimately bring them to large parks. Lyons et al. (2020) find that both service density and frequency are highly impactful on transit ridership, so increasing these measures in a way that helps accessibility to parks can potentially be synergistic with agency ridership goals. An outing to a large park where people spend an average of over 4 h is bound to take much of the waking day. As such, these trips are unlikely to take place on a weekday when transit service is most commonly concentrated. Transit agencies should identify potential T2P routes, those that connect disadvantaged neighborhoods to large parks, and ensure that frequencies and hours are not cut on the weekends for these routes. Further, transit agencies should consider targeted transit reroutings and shuttle buses to close the gaps between busy transit stations and large parks, as done in a few pilot initiatives in Los Angeles and Seattle (Los Angeles Metro, 2019; The Wilderness Society, 2019).

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi: https://doi.org/10.1016/j.ufug.2021.127055.

References


