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Exploring green gentrification in 28 global North cities: the role of urban parks and other types of greenspaces

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Abstract

Although cities globally are increasingly mobilizing re-naturing projects to address diverse urban socio-environmental and health challenges, there is mounting evidence that these interventions may also be linked to the phenomenon known as green gentrification. However, to date the empirical evidence on the relationship between greenspaces and gentrification regarding associations with different greenspace types remains scarce. This study focused on 28 mid-sized cities in North America and Western Europe. We assessed improved access to different types of greenspace (i.e. total area of parks, gardens, nature preserves, recreational areas or greenways [i] added before the 2000s or [ii] added before the 2010s) and gentrification processes (including [i] gentrification for the 2000s; [ii] gentrification for the 2010s; [iii] gentrification throughout the decades of the 2000s and 2010s) in each small geographical unit of each city. To estimate the associations, we developed a Bayesian hierarchical spatial model for each city and gentrification time period (i.e. a maximum of three models per city). More than half of our models showed that parks—together with other factors such as proximity to the city center—are positively associated with gentrification processes, particularly in the US context, except in historically Black disinvested postindustrial cities with lots of vacant land. We also find than in half of our models newly designated nature preserves are negatively associated with gentrification processes, particularly when considering gentrification throughout the 2000s and the 2010s and in the US. Meanwhile, for new gardens, recreational spaces and greenways, our research shows mixed results (some positive,

some negative and some no effect associations). Considering the environmental and health benefits of urban re-naturing projects, cities should keep investing in improving park access while simultaneously implementing anti-displacement and inclusive green policies.

1. Introduction

Fostered by global sustainability agendas (e.g. UN SDG 11), cities globally are increasingly mobilizing re-naturing projects towards green, sustainable, and healthy urban environments (Haase *et al* 2017). Those projects create or restore existing greenspaces and other vegetated environments, including parks, greenways or gardens, as well as blue spaces like waterfronts (Haase *et al* 2017, Taylor and Hochuli 2017, de Oliveira and Mell 2019). The adoption of re-naturing projects in cities is often motivated by existing evidence that green and blue spaces can address diverse urban socio-environmental and health challenges, including urban heat island effects, air pollution, water regulation and increased prevalence of non-communicable diseases (Kabisch *et al* 2017, de Oliveira and Mell 2019, Veerkamp *et al* 2021, Yang *et al* 2021).

At the same time, the implementation of re-naturing interventions may contribute to the attraction of new investment and place these areas at higher risk for gentrification—defined as socio-cultural and physical exclusion and displacement of underprivileged residents (i.e. minority racial/ethnic groups, working class individuals, non-white residents and immigrants) from the neighborhood (Glass 1964, Brown-Saracino 2010)—through a process known as green or environmental gentrification (Dooling 2009, Gould and Lewis 2017). The mechanisms by which re-naturing projects induce or accelerate gentrification are material and discursive. Greening contributes to increased property and land values as well as urban green grabbing practices (i.e. developers' appropriation of the financial and social benefits generated by nearby new or planned green amenities) (Safransky 2014, Czembrowski and Kronenberg 2016, García-Lamarca *et al* 2022). Re-naturing projects are further articulated around a green rhetoric that serves to (re-)brand cities (i.e. urban green boosterism) and eventually produce commodified environmental amenities (Garcia-Lamarca *et al* 2019, Triguero-Mas *et al* 2021). These projects may thus produce new types of social injustices (Anguelovski 2016, Rigolon and Németh 2018).

Green gentrification has been clearly documented in a diversity of urban areas, particularly linked with flagship interventions, such as projects in the US (e.g. the High Line Park in New York City or the BeltLine in Atlanta), in Europe (e.g. the Lene-Voigt Park in Germany, the Noorderpark in Amsterdam or the Limhamn Quarry National Natural Reserve in Sweden)

and also in East Asia (e.g. Cheonggyecheon Stream Restoration Project or the Gyeongui Line Forest Park in South Korea) (Loughran 2014, Sandberg 2014, Haase *et al* 2017, Kwon *et al* 2017, Weber *et al* 2017, Immergluck and Balan 2018, Jo Black and Richards 2020, Anguelovski and Connolly 2021).

To implement re-naturing agendas and projects able to address socio-environmental and health challenges while preventing gentrification and displacement, we must first understand how prevalent green gentrification is, the conditions under which it occurs, and the magnitude of its effects (Pearsall and Eller 2020). Yet, empirical quantitative evidence on the relationship between greenspaces and gentrification remains scarce, as much of the literature to date has been dominated by qualitative case study analyses of a specific city and/or of a particular neighborhood (Curran and Hamilton 2012, Loughran 2014, Anguelovski and Connolly 2021). Within this general paucity of quantitative studies investigating the relationships between greenspaces and gentrification at the citywide and cross-city levels, the few studies that do exist show mixed findings (Irwin 2002, Conway *et al* 2010, Kwon *et al* 2017, Anguelovski *et al* 2018, Maantay and Maroko 2018, Connolly 2019, Du and Zhang 2020, Pearsall and Eller 2020, Rigolon and Németh 2020, Shokry *et al* 2020, Chen *et al* 2021, Donovan *et al* 2021, Schinasi *et al* 2021, Kim and Wu 2022, Anguelovski *et al* 2022). Existing quantitative research commonly utilize either single socio-economic attributes to assess gentrification or one socio-economic variable at a time (Conway *et al* 2010, Kwon *et al* 2017, Du and Zhang 2020, Pearsall and Eller 2020, Kim and Wu 2022), the most common of these socio-economic variables being property values (Conway *et al* 2010, Du and Zhang 2020).

Further, few studies consider the heterogeneity of urban greenspace size, vegetation cover, species richness, amenities, legal protection, and other socio-environmental characteristics. A growing body of literature suggests that large-scale urban greening projects such as the BeltLine in Atlanta or the 606 rails-to-trails project in Chicago may induce environmental gentrification as they may be planned—at least partly—to increase property values (Loughran 2014, Kwon *et al* 2017, Immergluck and Balan 2018, Jo Black and Richards 2020, Chen *et al* 2021). However, a study of ten large and medium-size US cities found that park size did not have an impact on gentrification (Rigolon and Németh 2020). Meanwhile, smaller greenspaces, are conceptualized as part of a 'just green enough' approach that may not

trigger gentrification (Chen *et al* 2021) but may secure environmental and public health benefits of re-naturing interventions (Wolch *et al* 2014).

More specifically, different greenspace characteristics are related to greenspace types (e.g. parks, allotments or biodiversity areas) (Smith *et al* 2017) which may in turn lead to different gentrification patterns due to their diverse uses and variety of residents' appreciation (Amorim Maia *et al* 2020). For example, parks may be perceived as spaces of daily use for a variety of activities and may be strongly linked to neighborhood identity. Meanwhile, allotment or community gardens and biodiversity-rich areas such as nature preserves may be used as selling points, marketed as community spaces or valued for their environmental and biological worth. Less than a handful of studies (most of them from the US) have considered the associations between typologies of green spaces and property prices (Lutzenhiser and Netusil 2001, Czembrowski and Kronenberg 2016). However, scholars have clearly stated the importance of understanding how greenspace typologies may be linked to green gentrification (Pearsall and Eller 2020, Stuhlmacher *et al* 2022).

There is only scarce evidence on whether green gentrification is solely or more strongly linked with certain greenspace types and most of this evidence focuses in the US. The study by Rigolon & Németh reported that greenways located within half a mile of census tract centroids increased the odds of the census tract gentrification by over 200% (Rigolon and Németh 2020). A study in Portland showed that each new street tree planted in a census tract was associated with a $265 increase in tract-level median sales price 12 years after tree planting, thus impacting neighborhood affordability (Donovan *et al* 2021). Similarly, existing community gardens have been associated with increased gentrification in Brooklyn, New York (Maantay and Maroko 2018) and in St.Louis, Missouri (Braswell 2018). According to another recent study from New York City, passive (not associated with exerting recreational activities), natural (non-manicured, wild) greenspaces contribute to gentrification processes (Kim and Wu 2022). In the specific case of parks, one study in the north-eastern half of Barcelona found that areas around new urban parks experienced gentrification, but not in neighborhoods with housing units difficult to upgrade (Anguelovski *et al* 2018).

Considering this mixed evidence on green gentrification, we hypothesized that each type of greenspace might play a different role in green gentrification processes. Consequently, this study aimed to explore the association between different types of greenspaces and gentrification using quantitative data from a total of 28 cities in the Global North. More specifically, we investigated whether different types of greenspaces (parks, gardens, nature preserves, recreational spaces, and greenways) predict gentrification and whether these effects varied over time, between mid- and long-term gentrification, and between cities representing a variety of geographies and urban development contexts. Through our analysis, we derive city-level findings from tract-level observations.

2. Methods

2.1. Study design

We designed a multi-city study to assess improved access to different types of greenspace and gentrification processes over 1990–2016 in mid-sized cities in North America and Western Europe (supplemental material, page 3). With these criteria, we selected those mid-sized cities with strong greening agendas since the 1990s and available and reliable data on the variables of interest for our study, while aiming to include cities that represented different regions and different growth trajectories. This process led to including 28 cities in this study: 17 in North America (including 14 cities in the US: Atlanta (GA), Austin (TX), Baltimore (MD), Boston (MA), Cleveland (OH), Denver (CO), Detroit (MI), Louisville (KY), Milwaukee (WI), Philadelphia (PA), Portland (OR), San Francisco (CA), Seattle (WA), Washington DC (DC); and also three cities in Canada: Calgary, Montréal, Vancouver), and 11 in Western Europe (Lyon and Nantes in France; Bristol, Sheffield and Edinburgh in the United Kingdom; Amsterdam in The Netherlands; Barcelona and Valencia in Spain; Copenhagen in Denmark, Dublin in Ireland and Vienna in Austria) (figure 1).

2.2. Assessment of gentrification

In the absence of one universally accepted quantitative measure of gentrification, researchers have used a range of methods to assess if places are gentrifying and how rapidly (Freeman 2005, Ding *et al* 2016). In this study we calculated a gentrification score per small geographical unit (SGU) in each city and time period using a unified methodology described previously (Anguelovski *et al* 2022). In brief, our gentrification score is based on several measures of sociodemographic change and change in rent values. To build our gentrification score we calculate diversity in change across several sociodemographic constructs (ethnic/racial vulnerability, higher education, income, poverty, professional occupation) plus change in a real estate indicator (rental housing) by using Shannon's Equitability Index. That is, according to our composite score, gentrification occurs at the highest degree when several indicators change in a strong direction toward gentrification at the same time (Anguelovski *et al* 2022).

Accordingly, we obtained the most closely aligned variables that corresponded to the sociodemographic and real estate constructs previously stated for 2000, 2010 and 2016 (or the closest date possible to these years) in each SGU and city from national and local
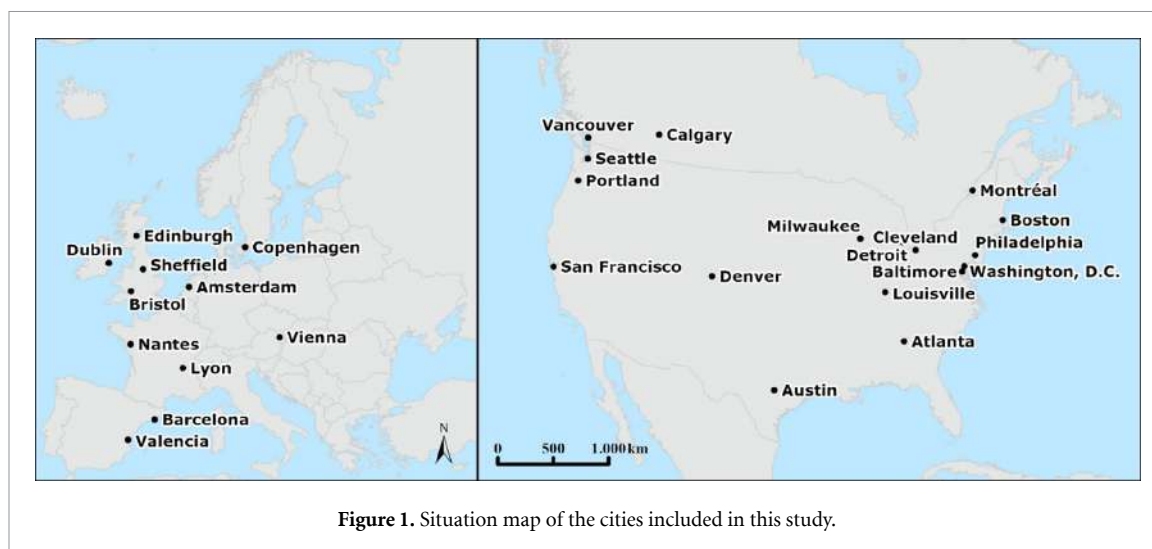
Figure 1. Situation map of the cities included in this study.

statistics offices (see tables S1–S3). Based on these data, we obtained two indicators of mid-term gentrification (gentrification for the 2000s, gentrification for the 2010s) and one indicator for long-term gentrification (gentrification throughout the decades of the 2000s and 2010s) (supplemental material, page 19).

2.3. Assessment of new greenspaces of different typologies

We obtained data for each city on different types of new greenspaces opened for public use between 1990 and 2016 using a combination of direct communications with city and non-profit organizations, city land records, published reports, media reports, historic imagery and city archival comprehensive searches (Connolly and Anguelovski 2021, Anguelovski *et al* 2022). We considered that new greenspaces were all those substantially vegetated publicly accessible spaces that had been inaugurated or publicly acquired (i.e. greenspaces that were formerly private spaces and were transferred to public ownership) during our period of study (i.e. 1990–2016).

Our study included five greenspace categories based on generic cross-city exclusionary definitions that built on common typologies of urban greenspace (Cvejic *et al* 2015, Smith *et al* 2017): parks, gardens, nature preserves, recreational areas, and greenways (find a summary of the classification in table 1, for a detailed description see (Connolly and Anguelovski 2021, Anguelovski *et al* 2022) and supplemental material, page 20).

Based on identified data we built the following ten indicators: *Parks pre ~ 2000s, Gardens pre ~ 2000s, Preserves pre ~ 2000s, Recreational pre ~ 2000s, Greenways pre ~ 2000s, Parks pre ~ 2010s, Gardens pre ~ 2010s, Preserves pre ~ 2010s, Recreational pre ~ 2010s, Greenways pre ~ 2010s.* The first five indicators (*Parks pre ~ 2000s, Gardens pre ~ 2000s, Preserves pre ~ 2000s, Recreational pre ~ 2000s* and *Greenways pre ~ 2000s*) denote the total area of—respectively—parks, gardens, nature

preserves, recreational areas or greenways added to each city SGU during the time period before the 2000s (i.e. before the start of the variable 'gentrification in the 2000's') plus 2 years (table S4). We included the 2 years overlap to account for the impact that announcing a greenspace creation or improvement may have on gentrification (Immergluck 2009). The last five indicators (*Parks pre ~ 2010s, Gardens pre ~ 2010s, Preserves pre ~ 2010s, Recreational pre ~ 2010s, Greenways pre ~ 2010s)* indicate the same as the previous five categories, but for the time period before the 2010s and 2 years during the time-period included in that gentrification variable, following the same logic as for the pre ~ 2000s indicators.

2.4. Covariates

Based on previous literature, we selected our study covariates. *Distance from the SGU centroid to the city centre* and SGU *population density per square kilometer in 2010* and *change in population density between the different time points we studied* was calculated by the research team using ArcGIS 10.6 software. SGU *green coverage prior to 1990* was also estimated using existing databases and ArcGIS 10.6 software. We also assessed the number of *public transit stops added* to the SGU immediately before and during the first 2 years of the studied decade using Google maps, Wikipedia and city level planning documents to identify the location of all new rail and bus stops. The number of *new residential buildings* built in the tract during each time period analyzed was derived from national and state statistics office reports, local building permit databases and lot-level tax or cadastral files.

2.5. Statistical analyses

We developed Bayesian hierarchical spatial models for estimating the relationships between gentrification and our variables of interest (i.e. new greenspaces), while adjusting them for the relevant covariates. More

Table 1. Typology of greenspaces considered in this study, including definition, sub-types and relevant aspects when evaluating green gentrification.

New greenspace type	Definition	Spaces comprised in this type	Relevant aspects when evaluating green gentrification
Parks	• Accessible, high-quality opportunities for informal recreation and community events. These spaces include a variety of features such as formal footpaths, play space, sports areas, trees, planted beds and/or ponds.	• Comprises all urban parks, ornamental gardens, parterres, and green plazas that are designated as vegetated areas.	• They offer a broad range of health promotion and recreational possibilities, including enhancing social networks with neighbors. These spaces are also a prominent space of urban biodiversity (Cvejic *et al* 2015). • We considered that these spaces may increase neighborhood attractiveness as parks may be perceived as spaces to use daily to promote and prevent one's health.
Gardens	• Spaces reserved for a defined set of gardeners to grow food or aromatic plants.	• Includes community and allotment gardens.	• These greenspaces are spaces for social interactions, while being places of food provisioning and physical activity (Cvejic *et al* 2015). • We considered that these spaces may be attractive to the first waves of gentrifiers as spaces to socialize and feel part of the neighborhood community.
Nature preserves	• Areas designated as protected from development and allowed to grow naturally in a relatively undisturbed state. These areas are residual natural habitats, planted or vacant land that has been colonized by vegetation and wildlife. They are often meant to protect biodiversity. • In our study, when there was a doubt about the legal protection status of the greenspace, the space was considered a park instead of a nature preserve.	• Includes urban forests, biodiversity areas, conservation areas, nature reserves and protected areas.	• These spaces are biodiversity hotspots, at the same time as they provide cooling, air pollution, carbon sequestration and water regulation. They may also be important source of certain foods and raw materials (Cvejic *et al* 2015). • We considered that these spaces may increase neighborhood attractiveness for those particularly interested in and those who value wildlife conservation, biodiversity and environmental education or those interested in living in less densely populated areas, surrounded by larger greenery.

(Continued.)

Table 1. (Continued.)

New greenspace type	Definition	Spaces comprised in this type	Relevant aspects when evaluating green gentrification
Recreational spaces	• Natural and artificial playing surfaces. Large and generally flat areas of grassland or specially designed surfaces, used primarily for designated sports i.e. playing fields, tennis courts, bowling greens.	• Sport fields opened for use (e.g. not within an enclosed stadium) and municipal recreation centers largely comprised of attached green areas.	• These spaces are particularly relevant as physical activity promoting amenities (Smith *et al* 2017). • We considered that these spaces may not prominently lead to green gentrification, as other similar grey spaces may provide similar services to residents.
Greenways	• Linear greenspaces designed for people to move through them. They may link different areas within a city as part of a designated and managed network and used for walking or cycling, or linking urban greenspaces and/or or cities to their surrounding cities, towns, countryside or country parks • In this study we considered that greenways did not have the amenities of parks but could be protected spaces (i.e. when a greenspace was both a greenway and a park was considered a park; but when it was both a greenway and a nature preserve it was considered a nature preserve).	• Includes riparian, natural and other vegetated corridors, greenbelts, and linear promenades with substantial vegetation.	• These spaces may have very different impacts according to their vegetation. Certain greenways structures may increase bird and insect richness and abundance or provide cooling, wind-control, air pollution and carbon sequestration (Cvejic *et al* 2015). • We considered that greenways role in green gentrification may be strongly dependent on city characteristics (residents' commuting, city structure).

specifically, we developed a model per city and gentrification time period so we had a maximum of three models per city: (a) one model with gentrification in the decade of the 2000s as the outcome variable and *Parks pre ∼ 2000s, Gardens pre ∼ 2000s, Preserves pre ∼ 2000s, Recreational pre ∼ 2000s,* and *Greenways pre ∼ 2000s* as the exposure variables of interest; (b) one model with gentrification in the decade of the 2010s as the outcome variable and *Parks pre ∼ 2010s, Gardens pre ∼ 2010s, Preserves pre ∼ 2010s, Recreational pre ∼ 2010s,* and *Greenways pre ∼ 2010s* as the exposure variables of interest; and (c) one model with gentrification considering the decades of the 2000s and 2010s as the outcome variable and *Parks pre ∼ 2000s, Gardens pre ∼ 2000s, Preserves pre ∼ 2000s, Recreational pre ∼ 2000s, Greenways pre ∼ 2000s* as the exposure variable of interest).

We reported the estimates of the associations between gentrification and each independent variable using posterior probability values (postprob-value). These postprob-values indicate the probability that each estimate that represents the effect of each independent variable on gentrification is greater than zero. Note that this value is a measure of the relevance for each independent variable, so are not to be interpreted in the same way as traditional *p*-values (supplemental material, page 23).

3. Results

3.1. SGU characteristics
From the 28 cities included in our studies, those with SGUs with higher population density were those in the United Kingdom, Ireland and Nantes, while those that extended more beyond the city center were all US cities (Austin, Detroit and Seattle) (table 2). In all our cities, 50% of the SGU had not had any new public transport stops built before the 2000s or before the 2010s. The cities where a higher number of public transport stops had been built in a SGU before the 2000s were all in Europe (Barcelona, Dublin, Lyon, Nantes and Sheffield) while before the 2010s the cities with a higher number of public transport stops built in a SGU were in Barcelona, Portland, San Francisco and Nantes. The cities where a high number of new residential buildings per SGU was sustained over time were in North America (i.e. Portland and Vancouver). In contrast, the cities with an average higher SGU green coverage before the start of our study period were in Europe (Barcelona, Copenhagen, Edinburgh, Valencia and Vienna).

The average newly inaugurated and acquired greenspaces at the SGU level differed widely among greenspace types (figure 2). Parks were the spaces with the highest area built per SGU from all greenspace types in terms of the 95th percentile (pre ∼ 2000s values being 95th percentile = 230.93 and pre ∼ 2010s 95th percentile = 25.19, data not shown) and also

in terms of the maximum values (pre ∼ 2000s maximum is 6042.86, while pre ∼ 2010s one is 1424.76). More specifically, when exploring the value of the 95th percentiles, Lyon, Amsterdam and Valencia had the highest values of park area built pre ∼ 2000s, while Nantes, Copenhagen and Amsterdam had them for the values pre ∼ 2010s. The rest of greenspace types (gardens, nature preserves, recreational and greenways) had 95% of their values of areas built below five and maximum values below 2000.

SGU average gentrification scores were generally higher in the US, particularly in Baltimore, Detroit and Philadelphia in the 2010s. In contrast, they were generally lower in Europe: Edinburgh in the 2000s, Valencia in the 2000s and Vienna throughout the 2000s and the 2010s (figure 3).

3.2. Analyses on gentrification and different types of new greenspaces altogether
Overall, when considering together mid-term gentrification (in the decade of the 2000s, in the decade of the 2010s) and long-term gentrification (through the decade of the 2000s and 2010s), we found associations with several factors, with distance to the city center and new parks being the most relevant ones (figure 4, tables S5 and S6). More specifically, we found that—in the presence of other covariates—new parks were positively associated with gentrification processes in more than half of our models. We also found suggestive evidence that newly designated nature preserves were negatively associated with gentrification processes (i.e. negative links in half of our models). Meanwhile, for new gardens, recreational spaces and greenways we did not find consistent results across cities.

3.3. Analyses on gentrification and different types of new greenspaces separately by mid-term and long-term gentrification
Our findings of new parks being positively associated with gentrification processes in more than half of our models remained when considering both mid- (in the decade of the 2000s and particularly in the decade of the 2010s) and long-term gentrification processes (figure 4, tables S5 and S6). For example, in the cities of Atlanta, Boston, Denver, Louisville, Milwaukee, Portland, San Francisco, Seattle, Vancouver, Barcelona and Dublin our data showed links between new parks and both mid-term gentrification and long-term gentrification processes. Moreover, in Austin, Cleveland, Washington D.C., Bristol, Copenhagen, Nantes, and Vienna new parks were associated with mid-term gentrification processes.
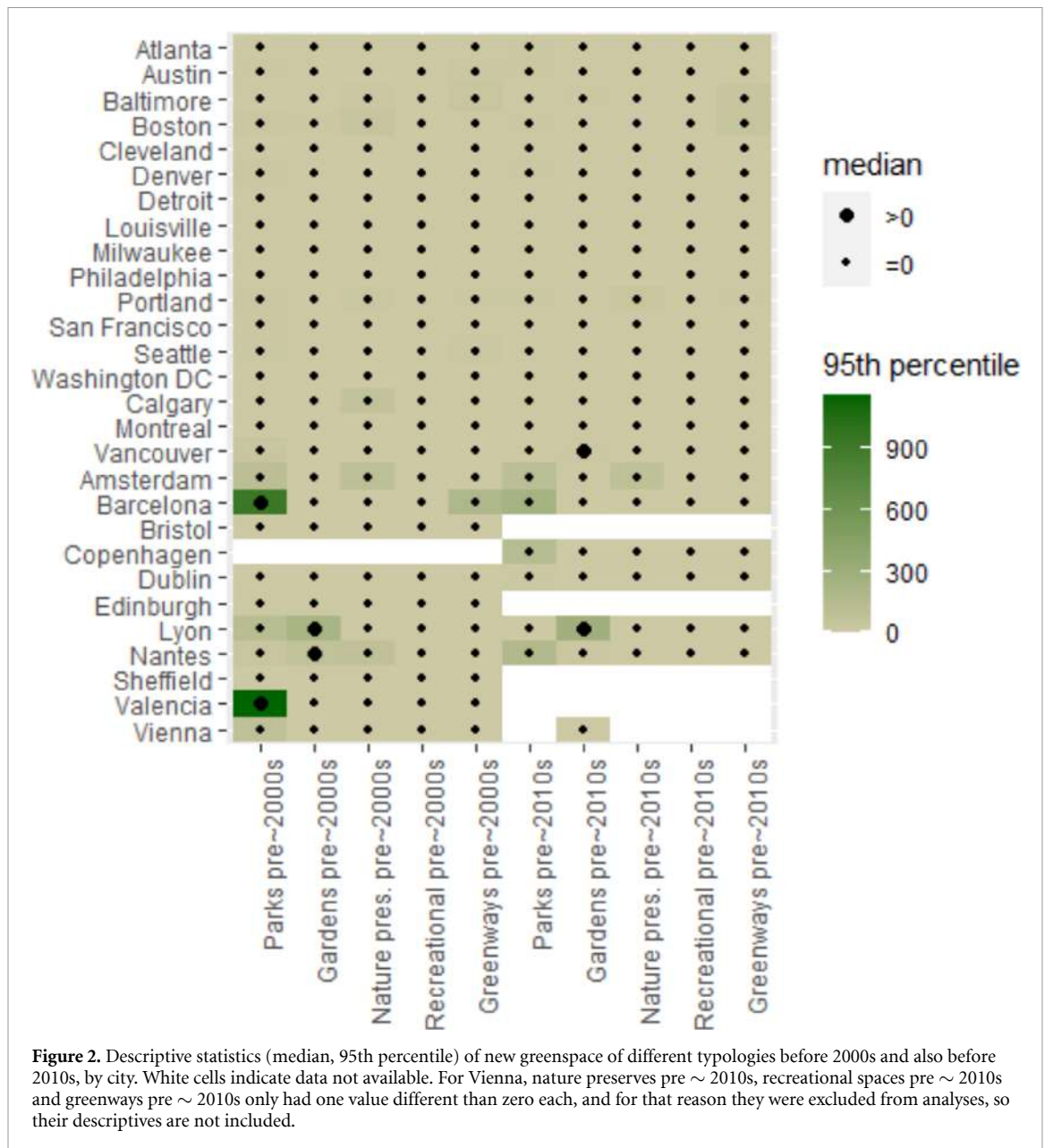
However, the negative association between that newly designed nature preserves and gentrification processes were more consistent for long-term gentrification processes (figure 4, table S6) than for mid-term gentrification (table S5). Indeed, we found that more area of newly designated nature preserves

Table 2. Descriptive statistics of census tract (SGU) characteristics, by city.

	Centre [metres]: mean (sd)	Number of public transit stops added…		New residential building built in the tract …		Green coverage prior to 1990 [ha]: mean (sd)	Inhabitants per square kilometer in 2010 [Inhab./km2: mean (sd)]
		pre2000s (stops/year: median (95th pct))	pre2010s (stops/year: median (95th pct))	pre2000s (buildings/year: median (IQR))	pre2010s (buildings/year: median (IQR))		
Atlanta	14 940 (9902)	0 (0.06)	0 (0)	0.02 (0.06)	0 (0.01)	0.04 (0.08)	1451 (1057)
Austin	20 019 (14 261)	0 (0)	0 (0.13)	0.50 (5.70)	0.20 (4.60)	0.05 (0.09)	1258 (1285)
Baltimore	4986 (2592)	0 (0.17)	0 (0)	0 (0)	0 (0)	0.25 (0.29)	4686 (3396)
Boston	5615 (3382)	0 (0)	0 (0)	0 (0.01)	0 (0)	0.36 (0.47)	9449 (6744)
Cleveland	12 359 (5858)	0 (0)	0 (0)	0.50 (1.90)	0 (0.20)	0.08 (0.17)	1978 (1193)
Denver	7391 (4651)	0 (0.17)	0 (0.13)	1.40 (5.95)	0.60 (3.20)	0.13 (0.17)	2808 (1,534)
Detroit	16 914 (8953)	0 (0)	0 (0)	0 (0.60)	0 (0)	0.05 (0.11)	1937 (1020)
Louisville	11 763 (6450)	—	—	0 (0.10)	0.20 (0.75)	0.06 (0.12)	1448 (858)
Milwaukee	8094 (4468)	—	—	0 (0.20)	0 (0)	0.01 (0.03)	3081 (2186)
Philadelphia	8236 (5316)	0 (0)	0 (0)	0.30 (2.30)	0.20 (1.00)	0.21 (0.28)	7430 (4188)
Portland	9048 (6448)	0 (0.17)	0 (0.32)	4.25 (7.55)	4.00 (7.55)	0.07 (0.10)	2513 (1479)
San Francisco	4875 (2815)	0 (0.17)	0 (0.38)	1.65 (2.95)	0.20 (0.80)	0.39 (0.47)	11 563 (8915)
Seattle	17 582 (11 196)	0 (0)	0 (0.13)	0 (1.80)	0 (2.70)	0.06 (0.12)	2115 (2177)
Washington DC	5250 (2419)	0 (0.08)	0 (0)	0 (0.01)	0 (0)	0.37 (0.34)	6195 (4398)
Calgary	8553 (3817)	0 (0)	0 (0.14)	0 (1.10)	0.20 (7.05)	0.13 (0.23)	2708 (1579)
Montreal	8710 (6001)	0 (0)	0 (0)	0.10 (0.30)	0 (0)	0.29 (0.28)	7833 (5472)
Vancouver	4958 (2436)	0 (0.08)	0 (0.14)	5.65 (10.98)	5.60 (10.75)	0.18 (0.21)	7103 (5522)
Amsterdam	3950 (2365)	0 (0)	0 (0)	0.33 (1.92)	0.13 (0.69)	0.38 (0.32)	10 468 (7627)
Barcelona	3418 (1614)	0 (1.00)	0 (1.00)	0.10 (0.30)	0 (0)	0.98 (1.16)	43 103 (24 066)
Bristol	3828 (2155)	—	—	2.22 (4.44)	—	0.60 (0.39)	6078 (3496)
Copenhagen	3301 (1652)	—	0 (0)	—	0 (0.17)	0.86 (1.22)	15 353 (11 298)
Dublin	4085 (1885)	0 (0.43)	0 (0)	—	—	0.36 (0.26)	6512 (4273)
Edinburgh	4387 (2861)	0 (0)	—	0.33 (4.17)	—	1.15 (0.99)	7627 (6278)
Lyon	2493 (1249)	0 (0.33)	0 (0.14)	—	2.64 (9.75)	0.58 (0.39)	15 756 (9990)
Nantes	2712 (1331)	0 (0.44)	0 (0.22)	—	11.57 (14.36)	0.16 (0.17)	6867 (3615)
Sheffield	5025 (2817)	0 (0.33)	—	1.11 (4.33)	—	0.51 (0.40)	4833 (510)
Valencia	2387 (1630)	0 (0.25)	—	0.10 (0.30)	—	0.94 (1.01)	31 189 (19 437)
Vienna (central)	4543 (2673)	—	—	—	—	0.83 (0.73)	14 644 (11 051)

Notes: Indicates that no data was available.

Mean (standard deviation (sd)) is reported for continuous parametric variables. Median (interquartile range (IQR)) is shown for continuous non-parametric variables, with the exception of those with a high percentage of zeros, for which median (95th percentile (95th pct)) is reported.

Figure 2. Descriptive statistics (median, 95th percentile) of new greenspace of different typologies before 2000s and also before 2010s, by city. White cells indicate data not available. For Vienna, nature preserves pre ∼ 2010s, recreational spaces pre ∼ 2010s and greenways pre ∼ 2010s only had one value different than zero each, and for that reason they were excluded from analyses, so their descriptives are not included.
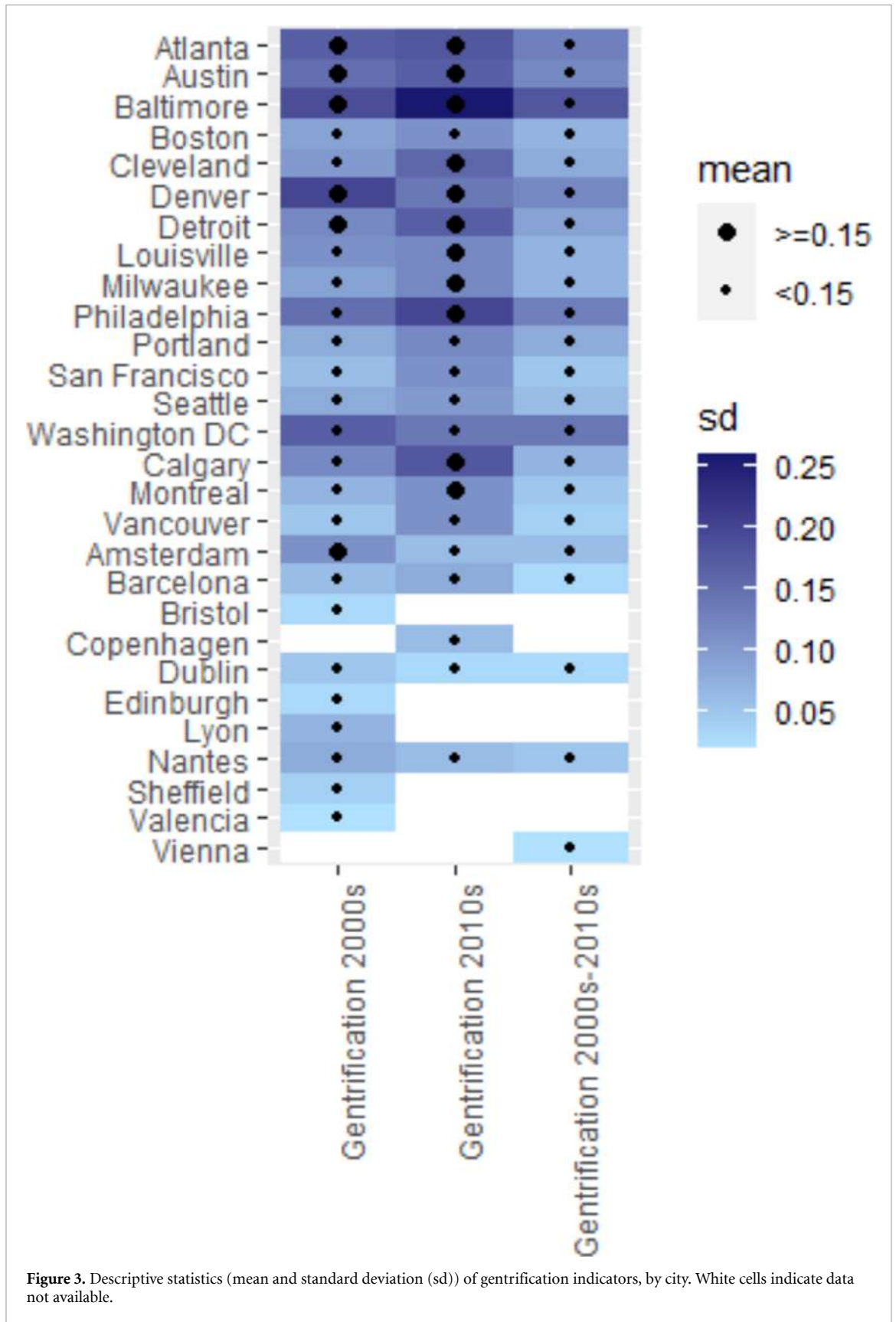
was associated with smaller long-term gentrification indexes for all cities for which we had data except for three: Boston (postprob-value = 0.70), Calgary (postprob-value = 0.65) and Nantes (postprob-value = 0.79).

We also found that long-term gentrification was positively associated with new gardens and greenways inaugurated between the start of our study period and the 2000s in more than half of our models. Last, our results indicated some positive relationships between long-term gentrification and new recreational spaces (in Atlanta, Baltimore, Denver, Washington D.C: and Barcelona) inaugurated between the start of our study period and the 2000s (i.e. positive associations in half of the relationships we explored). In contrast, we found inconsistent results between new greenways, recreational spaces and gardens and mid-term gentrification indexes.
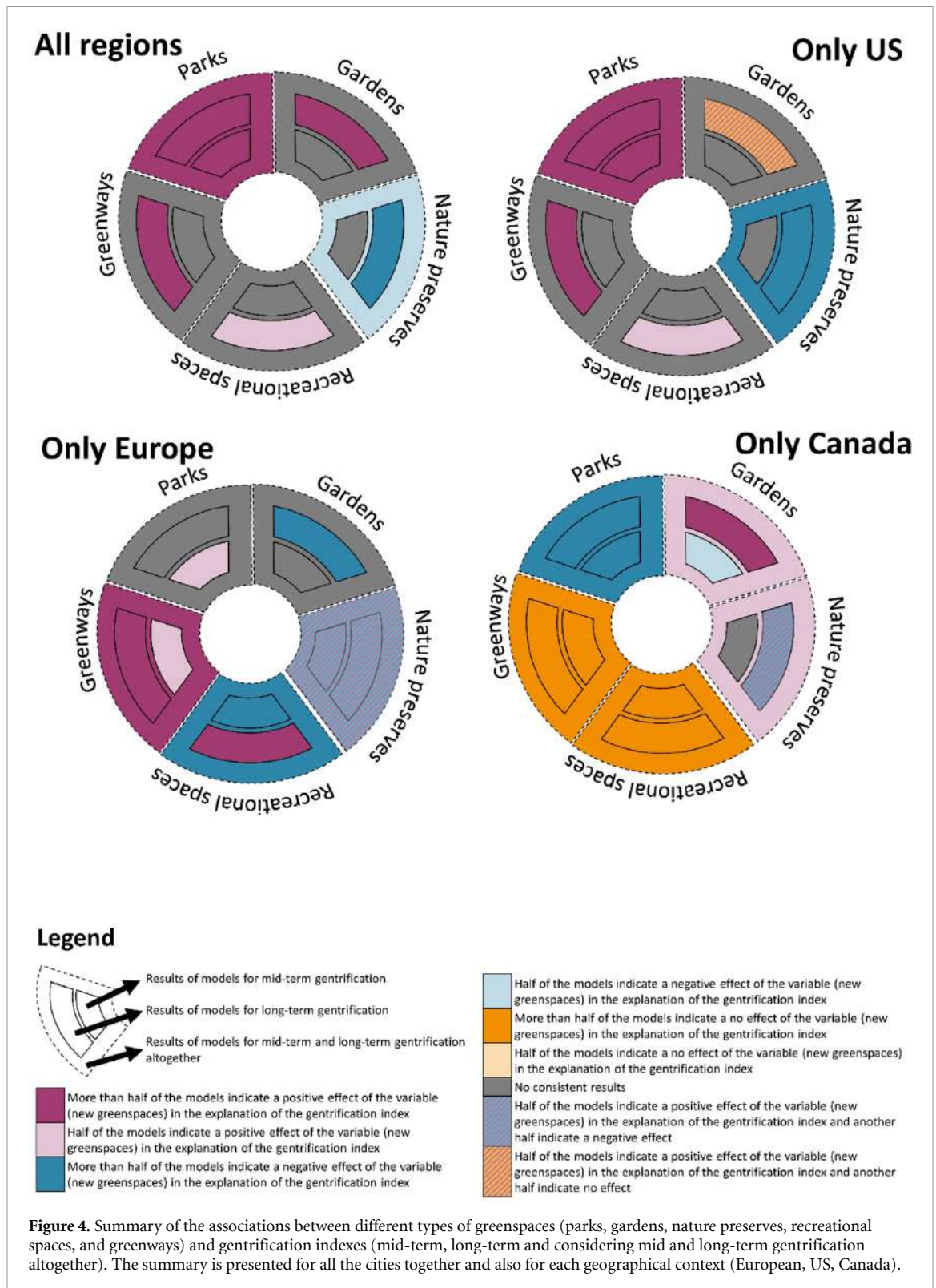
3.4. Analyses on gentrification and different types of new greenspaces over time periods

When exploring if associations between new greenspaces and gentrification were sustained over different time periods we did not find any clear patterns (tables S5 and S6). Only for parks, gardens and greenways we did find sustained associations over time in some cities. We found that parks pre ∼ 2000s were positively linked with gentrification in the 2000s while parks pre ∼ 2010s were associated with increased gentrification in the SGU in the 2010s in Atlanta (postprob-value = 0.96 for the association with parks pre ∼ 2000s and postprob-value = 0.99 for the association with parks pre ∼ 2010s), Cleveland (postprob-value = 0.68 and postprob-value = 0.87), Denver (postprob-value >0.99 and postprob-value = 0.66), Louisville (postprob-value = 0.89 and postprob-value = 0.77), Seattle (postprob-value = 1.00 and

Figure 3. Descriptive statistics (mean and standard deviation (sd)) of gentrification indicators, by city. White cells indicate data not available.

postprob-value = 0.75) and Nantes (postprob-value = 0.99 and postprob-value = 0.73). The same trend was found in Denver for greenways and in Milwaukee, Seattle and Nantes for gardens. Moreover, we found some indications of the relationship between new parks and gentrification increasing over time as—from the cities we included in the study—we found a higher proportion of the associations between parks and gentrification for gentrification in the 2010s than in the decade of the 2000s.

Figure 4. Summary of the associations between different types of greenspaces (parks, gardens, nature preserves, recreational spaces, and greenways) and gentrification indexes (mid-term, long-term and considering mid and long-term gentrification altogether). The summary is presented for all the cities together and also for each geographical context (European, US, Canada).

3.5. Analyses on gentrification and different types of new greenspaces by geographical area

Comparisons of our results by geographical area revealed that positive associations between new parks and gentrification were predominantly found in the US, both overall and when looking only at mid- or long-term gentrification processes (figure 4, tables S5 and S6). For example, from all the US cities we included in our study, only in Baltimore, Detroit and Philadelphia our data did not reveal a positive link between parks and gentrification. In contrast, we did not find any clear patterns for parks in Europe, while in Canada we mostly found negative associations between parks and gentrification in most cities.

Similarly, our findings on newly designated nature preserves being negatively linked with

gentrification, particularly when considering long-term gentrification, were also mostly found in the US, where from all the US cities for which we had data, only in Boston we found links between newly designated nature preserves before the 2000s and gentrification processes in the decades 2000s–2010s. Meanwhile, in Europe and Canada no consistent patterns were found for newly designated nature preserves and gentrification processes. Last, the positive relationships we found between new gardens and gentrification were predominantly found in Canada and those for greenways were mostly found in Europe and the US.

4. Discussion

Overall, this unique multi-city study on the relationship between different types of greenspaces and gentrification clearly demonstrates that—apart from other commonly recognized factors such as distance to the city center—different types of newly inaugurated or acquired greenspaces have a different role in the gentrification process. Through an international analysis that reveals trends at the city-level based on SGU data, we find that parks are the type of greenspaces more consistently positively associated with gentrification processes. We also found some indications of newly designated nature preserves being negatively associated with gentrification processes, particularly when considering long-term gentrification processes (i.e. throughout the 2000s and the 2010s) and in the US. Meanwhile, for new gardens, recreational spaces and greenways our research shows mixed results.

Our research indicates that different types of greenspace can be associated with gentrification (solely or together with other factors such as distance to the city center). This finding is aligned with most of the existing evidence (Lutzenhiser and Netusil 2001, Czembrowski and Kronenberg 2016, Kwon *et al* 2017, Maantay and Maroko 2018, Rigolon and Németh 2020, Chen *et al* 2021, Kim and Wu 2022).

Our findings about parks as the greenspace type more consistently positively associated with gentrification processes are partly in line with previous scientific evidence. A study in Barcelona had already found that new parks built in the old town or in traditionally industrialized neighborhoods explained gentrification processes (Anguelovski *et al* 2018). However, Rigolon & Németh did not find a link between acreage of new parks and gentrification in their pooled analyses of data from ten US large and medium-sized cities (Rigolon and Németh 2020). The differences in results with our study could be due to our research design including a more complete and refined set of indicators to calculate gentrification scores, controlling of spatial autocorrelation rather than using multilevel logistic regressions to estimate

the associations and also due to our study avoiding reverse causation (i.e. our investigation estimating the association between greenspace inaugurated or acquired at a time period and gentrification in a later period, while the study by Rigolon & Németh estimated the relationships between greenspace and simultaneously-occurring gentrification).

Our results may indicate that the gentrification effects related to urban greening agendas and associated green branding (Garcia-Lamarca *et al* 2019) may be strongly centered on parks. 'Normative' aesthetics and recreational possibilities may make parks the type of greenspaces that best encompass familiarity, favorability and uniqueness and provide more utility to neighborhood residents. All these factors are linked with green branding and gentrification and may increase willingness to pay for these neighborhoods (Chan 2015, Amorim Maia *et al* 2020). For example, aspects such as ornate landscapes, with manicured garden designs and fences (which might give high feelings of security) could make parks more aestheticized and attractive to gentrifiers and real estate developers (Chen *et al* 2021). They are also those spaces where racialized minorities might find themselves more controlled by police, surveilled, and criminalized (Anguelovski and Connolly 2021, Hoover and Lim 2021).

Moreover, the higher prevalence we found of positive relationships between new parks and gentrification in more recent times (i.e. from the cities we included in the study, we found a higher proportion of associations between new parks and gentrification for gentrification in the 2010s than in the decade of the 2000s) are in line with findings from recent studies identifying the 2010s as the decade in which cities have deployed a more articulated and formal green branding (Gulsrud *et al* 2013, Andersson 2016, Garcia-Lamarca *et al* 2019). This comprehensive green branding may be the result of developers and cities around the world aiming at reproducing the marketing and private profit-making 'success' of New York's High Line and Atlanta's BeltLine (Loughran 2014, Haase *et al* 2017, Weber *et al* 2017, Immergluck and Balan 2018, García-Lamarca *et al* 2022). The opening of both green interventions was linked to an increase in property values (and green gentrification), which cities and developers potentially imported to other contexts (Haase *et al* 2017, Rigolon and Németh 2020).

We are aware of only three previous studies on the impact of other typologies of greenspaces (such as nature preserves, gardens, recreational spaces or greenways) on gentrification. A previous study demonstrated that greenways created between 2008 and 2016 increased the odds of census tract gentrification, but those created between 2000 and 2008 were not linked to gentrification (Rigolon and Németh 2020). Other research found that the availability of community

gardens was modestly associated with gentrification (Braswell 2018, Maantay and Maroko 2018). Our findings add to the existing, yet still scarce, evidence. The heterogeneity of associations we found may indicate that gardens, recreational spaces and greenways are types of greenspaces with very diverse accessibility, uses, aesthetic, and functional characteristics and roles in gentrification processes. It may also be that other factors from which we did not have data (such as presence of vacant land) may influence the role of community gardens, recreational spaces or greenways in gentrification processes.

Our findings that nature preserves are negatively associated with gentrification processes, particularly when considering long-time gentrification processes or in US cities, are novel and have not been explored before. We hypothesize that most of the nature preserves included in our analyses and categorized as new greenspaces are in fact greenspaces that were already present before our period of study (either before the 1990s or before the 2000s), but which became enclosed, formalized as protected areas or whose management changed from private to public during our study period (1990–2016). These legal or administrative changes potentially may not translate into new value creation. An alternative explanation could be that preserves may not be perceived nor allowed (like La Petite Amazonie in Nantes) as formal accessible green spaces for daily use or may even be associated with feelings of fear or insecurity for some people due to their wildness (Lyytimäki and Sipilä 2009, Rupprecht and Byrne 2014).

The differences we find between the US and Canada and Europe in the occurrence of green gentrification may also be due to distinct policy and planning contexts, with European cities generally benefiting from the greater presence of anti-displacement tools and equitable greening practices (Oscilowicz *et al* 2022) in comparison with US cities. Last, the importance of spatial effects found in our analyses indicates that new greenspaces located near gentrifying neighborhoods are more susceptible to gentrification than those located far away, which is in line with previous evidence (Pearsall and Eller 2020). This may suggest that greenspaces serve as an anchor to support gentrification processes already existing in the vicinity, but do not have an impact alone.

Our original and methodologically robust study explores the associations between a broad range of types of greenspaces and gentrification. To our knowledge, it is the first to investigate these associations in a broad range of cities in Europe, Canada and the US, across different time periods using rigorous novel methods, namely a Bayesian spatial analysis approach, to do so. More specifically, our control of spatial autocorrelation and a broad range of potential confounders and our gentrification assessment with a score developed to be valid in different geographical

contexts and time periods while considering the heterogeneity of these different cities are strong elements of our study. Our study design also prevents reverse causation, as neighborhood gentrification cannot casually influence new greenspace creation, inauguration, or improvement in previous years.

Our study, however, also faces some limitations. Our aim to compare a broad range of cities in different regions prevented us from using a completely consistent data protocol, so we had to find compromises in the use of time periods and variables across the different cities. We use SGU as the unit of analysis, but SGU limits do not determine gentrification processes and we had low variability in our greenspace variables (i.e. a lot of our census tracts had no new greenspaces). Green gentrification may be better assessed through analyses using greenspaces as the unit of analysis, despite the high level of data process that developing these measures can need may make them inefficient at large scale. Finally, our study includes a very detailed dataset of types of new greenspaces, but factors such as neighborhood historic significance and characteristics, greenspace size or presence of private greenspaces that may be correlated with both gentrification and public greenspaces, and that previous studies have explored as explanatory variables (Anguelovski *et al* 2018, Chen *et al* 2021, Donovan *et al* 2021, Kim and Wu 2022) were not included.

5. Conclusions

In summary, our study reveals that parks—together with other factors such as proximity to the city center—may contribute to gentrification processes (i.e. positive associations in more than half of our models), particularly in the US context, except in historically black disinvested postindustrial cities with an abundance of vacant land. In contrast, nature preserves, greenways, gardens and recreational spaces are types of greenspaces with diverse roles in gentrification processes (some positive, some negative and some no effect associations). We conclude that the phenomenon of green gentrification in North America in particular, and in Europe to some extent may be reinforced more by parks than other greenspaces types.

Both gentrification and an increase in re-naturing projects are well-described in cities around the world (Lees 2012, Haase *et al* 2017, Navarrete Escobedo 2020). Moreover, green gentrification is growingly reported in different locations (Quinton *et al* 2022). Accordingly, although our findings refer to Europe and North America, they should be considered in other contexts and future studies should explore if our results are replicated in other geographical locations such as South America or Asia.

Future studies should further explore the potential impact of different characteristics and other attributes of greenspace on gentrification, building on the attributes already explored to produce comparable evidence. When doing so, it will be important to investigate a combination of types and biophysical characteristics (e.g. parks of different size, parks with different attributes), including socio-cultural traits related to greenspaces attractiveness and perception (van Vliet *et al* 2020, Kim and Wu 2022) and to use greenspace as the unit of analysis (as previously done by (Anguelovski *et al* 2018). The main objective of our study was to investigate whether different types of greenspaces impact gentrification. However, as previous studies have suggested, future lines of research should also explore if the causal link is inversed (i.e. if gentrification processes explain the creation and designation of new greenspaces) (Shokry *et al* 2020, Reibel *et al* 2021).

Considering the environmental and health benefits of urban re-naturing projects, we are calling for cities to keep investing in improving park access and availability in under-privileged neighborhoods while simultaneously implementing anti-displacement and green inclusive policies (Oscilowicz *et al* 2022). Withholding greenspace investment and associated benefits would indeed risk reinforcing the health inequities and environmental injustices that socially underprivileged residents already face.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

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