Maintaining and Improving Biodiversity in Urban Centers: Landscape Spatial Design in Mexico City and New York City

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Abstract

Context

Large cities contain different sizes and distributions of green spaces in a sea of buildings and roads. This urban landscape establishes the habitat for different species that persist in cities.

Objectives

How does this "archipelago" of habitat space function? How does the arrangement of green spaces affect plant and animal species' biodiversity and movement through this urban pattern?

Methods

By using Patch Analyst Metrics, we propose a novel method to analyze and improve the current spatial arrangement of green spaces using Mexico City and New York City, long-established urban areas.

Results

The two cities differ in the number, size, and spatial distribution of green spaces. Frequency analysis suggests that Mexico City has a high number of large green spaces for native species conservation; but most of them are in one vast cluster of green areas at the south. In New York City large spaces are distributed along the whole territory, comprising most potential habitats, but it has much more small areas. This spatial analysis shows particular areas in which both cities have the potential to add connectivity among existing green spaces for dispersal of many taxa of plants and animals.

Conclusions

Much data is available on the potential dispersion through cities, but a better framework for understanding the existing distribution is needed for future landscape decisions. Results suggest ways that new urban areas can better increase plant and animal movement patterns.

Introduction

The presence of green spaces in large cities provides many ecological services that improve the quality of urban life and the health of the human population (Elmqvist et al., 2015; TEEB, 2010). Ecological sustainability of urban green spaces is strengthened by high biodiversity and complex food webs so that changes in physical and biotic conditions do not diminish ecological functioning. Urban biodiversity can be high with many species present, even in large, historical cities (Aronson, Patel, O'Neill, & Ehrenfeld, 2017).

The distribution of green spaces directly impacts the ecological community of organisms that live there (Gilpin & Hanski, 1991). For example, species move at different rates and have different generation times. Genetic studies (e.g., Johnson and Munshi-South 2017) show population isolation among even closely placed urban patches. Consequently, biodiversity in a new urban green space will not replicate other spaces immediately but will build as surrounding species immigrate. This may happen very slowly or not at all, depending on the rate of disturbance and the presence of barriers in the landscape matrix, in a classic metapopulation process.

Consequently, cities with more green patches may have more favorable habitat types, stochastically, which can harbor more species.

Green spaces are reached at different dispersal rates by different taxa. In urban areas, the dispersal pattern is modified by the three-dimensional built landscape. The dense concentration of urban infrastructure acts as barriers that challenge species' ability to move to a new landscape, though there is much deviation in the ability of species to move through urban centers (Angold et al., 2006; Nielsen, van den Bosch, Maruthaveeran, & van den Bosch, 2014a). Additionally, there must be a favorable time sequence for movement to occur; plant habitat must be established before many animals can successfully colonize. The movement patterns are broad for some taxa, and the green spaces for them are functionally attached, not islands. In other cases, urban parks may be sinks for survival because the species cannot persist after colonizing, if the parks lack critical elements for a species' life history requirements.

Connectivity among green spaces affects the persistence of urban biodiversity (Bennett, 2003). Urban hardscape barriers and heights make functional distances in cities longer than in rural areas, even though the spatial scale is the same. This is similar to the "mountain passes are higher in the tropics" concept (Ghalambor, Huey, Martin, & T, 2006). Some urban barriers affect the height that animals or seeds must overcome and create shade, artificial light, wind tunnel, and heat island stressors to species' movements. Together, these spatial forces make the ability of species to navigate and colonize in cities quite different from in rural areas.

The findings of high urban biodiversity have been surprising as urban green spaces are often small and separated by this hardscape/infrastructure, which impedes the movement of many species and their propagules. The small area of many urban green spaces results in small population sizes that can lead to local extirpation by biotic or stochastic pressures (Collinge, 2009). These smaller areas have a relatively large edge/center ratio, creating an adverse effect on their quality, favoring species that can persist in those changed spatial conditions.

These problems of sustaining urban green spaces have led to the consideration of generating corridors or additional "stepping stone" green parcels to increase biodiversity (Bennett, 2003; Collinge, 2009). These types of connections may be more easily designed in new cities, where biodiversity planning can be arrayed from the start into the spatial pattern of the landscape. In contrast, old cities are constrained to support biodiversity by the pattern of urban infrastructure around existing, often isolated, green spaces.

In existing cities, ecological constraints are framed by several forces that influence the spatial distribution of habitats:

-        the type of ecosystem in which the city was established;

-        the culture that defines uses of urban space from time of first settlement to today;

-        history (growth rate, episodic disruptions) of the urbanization;

-        the socio-ecological zoning of the urban area;

- the economic forces that mold urban development over the decades.

These multiple determinants of urban structure constrain the possibility of maintaining or improving biodiversity (Clifton, Ewing, Knaap, & Song, 2008). Ecological improvements, however, can occur if planning concepts are better married to ecological principles (Harris, 1984; Hobbs & Saunders, 1993; Parris et al., 2018; Zipperer et al., 2000). Our study frames a method to map existing green spaces to improve the design and management of urban green areas for ecological structure and function within these constraints. Biotic communities in cities are affected by a foundation of at least four spatial characteristics:

1. The number of green spaces (figure 1a). Species diversity usually increases as the number and heterogeneity of areas increase, creating a mosaic of potential urban biota spaces. More areas buffer against stochastic extirpation in any one area. Also, different taxa require diverse niche spatial axes. Consequently, more taxa can be found if more individual spaces are present.

2. Area of green spaces (figure 1b). Larger areas may increase survivorship as each population usually can be more numerous, avoiding stochastic local extinctions. Larger areas also increase the probability that the parcels will contain soil, nutrient, water, and refuge conditions that can safely harbor species during unfavorable and changing climatic conditions.

3. Distribution of green spaces (figure 1c). Dispersal capacities vary widely among taxa, and increased distance can filter biodiversity. Urban parcels, even if geographically close, can be unavailable to species that have limited ability to migrate. For example, a framework for animal movement modes by the landscape architects Studio-MLA (2017), suggests a typology where different species can persist if there are contiguous surface paths (corridors), bypasses that avoid unfavorable surface zones (bridges), or are separated but close enough for regular aerial dispersal to succeed (patches). For example, flying species (and the seeds they carry) may move among patches even if inappropriate surface conditions separate them. Other species walk, crawl, or are carried by surface-bound transporters (fur, clothing, vehicles), but must remain earth-bound. Another way to categorize these movement styles is as wide travelers, pedestrians, homebodies (do not move from natal areas), and jumpers (saltators). Built conditions between green spaces may be so inhospitable that even common species may not move to nearby areas. This has been demonstrated, for example, by the significant genetic differences among mouse populations in New York City green spaces (Munshi-South & Kharchenko, 2010; Munshi-South & Nagy, 2014). Precise mapping of green space locations within old cities can improve our understanding of what biotic improvements are possible.

4. Quality of green spaces (figure 1d). The ability to support species' niches must be present. "Quality" is a metric that varies with each space's ability to provide the unique niche axes of each species. Urban areas so often have had past land uses that modified original conditions. The space now may be inadequate, even for regionally common species. Restoration science may not be able to remediate the space adequately to return to those conditions.

Many older cities have numerous green spaces, but this varies enormously among cities with different developmental histories (Fuller & Gaston, 2009). Similarly, many new urban greening projects have been designed over the past decades, but often without attention to the spatial interplay among new and old green spaces (Kemp, 2006). Here, we explore new methods to map and analyze the spatial conditions of urban

green spaces using data from two very large, established cities, Mexico City and New York City, whose current forms and infrastructure began 400-500 years ago. We ask for each city, what is the pattern of existing green spaces and what practical actions can be made to secure existing biodiversity and improve biodiversity? This is of importance in a time when climate and sea levels are rapidly changing, and current species diversity and abundance are expected to change significantly (Grimm et al., 2008). New land management actions (addition of green spaces, or new management of existing green spaces, for example) may be needed to maintain or improve the current ecological functions. The analyses aim to establish a method that can be used elsewhere to reach these goals.

Methods

Mapping protocols of the two cities were different because the data sources were created at different times and with different methods:

Mexico City (MXC) The distribution of the green spaces for Mexico City (figure 2a) was based on Landsat 8 satellite images of May 18, 2018, in which green spaces were identified from the Normalized Vegetation Index analysis (NDVI). Through this index, an area's photosynthetic activity is reported, the "greenness" of the plants. In general, this method assumes that photosynthetically active vegetation absorbs most of the red light and reflects much of the near-infrared light (Bannari, Morin, Bonn, & Huete, 1995). Surfaces without vegetation have a much more uniform reflectance across the entire spectrum of light. The NDVI is obtained by dividing the difference between the red and infrared spectra (Jones & Vaughan, 2010).

City of New York (NYC): The green spaces' base data were found on ArcGIS Online under: NYC_Parks_Properties_2016 and Green Space Paton, Green spaces in NYC [Feature Service by cp2983_columbia, 6-17-2017] (Paton, 2017) (figure 2b).

We used the Patch Analyst Extension in ArcGIS version 10.2 for a landscape analysis with patches (hexagons) of 500ha. We tested different sizes of hexagons and concluded that the 500ha could provide ecological information at this city scale. Patch Analyst was developed under the Spatial Ecology Program (Centre for Northern Forest Ecosystem Research) (Rempel, Kaukinen, & Carr, 2012). Variables generated in the patch were related to the spatial characteristics listed in the introduction (here we use the official names of the Patch Analyst Method): 1) Number of Patches (NumP) are the total number of patches per hexagon; 2) Mean Patch Size (MPS) is the average patch size inside; 3) Mean Nearest Neighbor (MNN) is the shortest distance to the fragment of the same nearest class in meters; 4) Total Core Area (TCA) is a measure of the amount of core (green) area in the patch (Subirós, Linde, Pascual, & Palom, 2006). These hexagon maps give spatial guidance on designing corridors for biodiversity and sustainability based on ecological landscape principles. Descriptive statistics were applied to evaluate the abundance patterns of green spaces based on indexes per hexagon.

In both cities, those spaces smaller than 0.5 hectares were selected and eliminated since a 0.5 ha area could be the minimum size for many species' survival capacities and home range (Rudd, Vala, & Schaefer, 2002a). The spaces featuring the Brooklyn Green-wood Cemetery, Floyd Bennett Field, and the green space between Hendrix and Betts Creeks were added by tracing and editing. Although these are not parks, they have landscape vegetation that is consistent with mapped parks. The natural protected area in the south of Mexico

City also was included as a large bulk of green space. Then by exporting the Attribute Table of each shapefile, the number of green spaces and their respective areas were obtained.

Each variable was divided into five categories, which helped to analyze frequency patterns of green space size and the whole city's distribution. Geographically classes helped to visualize the green spaces' characteristics within each city. We emphasized differentiating small values of the variable by splitting more categories than in bigger values. With this in mind, the only variable classified equally among patch values was the Number of Patches (NumP). The Mean Patch Size (MPS) variable were sorted into the following five categories: None (N). Small (S) = 0.5-5 ha. Medium (M) = 5.1-25 ha. Large (L) = 25.1-100 ha. Extra Large (XL) = larger than 100 ha. These categories fit with dispersion models presented in Rudd et al. (2002). For the Mean Nearest Neighbor, (MNN) variable classification considered the importance of the first 200 m between green spaces since those are critical for many species' dispersal. The first category was between 0 - 50m, the second 50 - 100m, the third, 100 - 200m, fourth 200 – 400m and the fifth > 400m

Finally, the Total Core Area (TCA) variable, in this case we used a percentage of green space covering the total of the hexagon area. The first three categories embrace up to 20% of the hexagon covered by green space, while the last category covers more than 50% of the hexagon.

Results

The two cities have contrasting patterns of green space that have been developed over the centuries, based on the geologic and topographic patterns of the landscape. In both cities, the existing green spaces are surrounded by the urban matrix, roads, residential districts, and other infrastructure, constrained from growing by urban needs and history.

In MXC (figure 2a), substantial green spaces are in the southern section of the city. This is an area of mountainous topography that had small settlements during the pre-Colombian era. During the colonial period, settlement continued to be focused on the northern half, the lowlands. Consequently, much of the land in the south is a continuous forest and grassland mosaic occupying more than 90% of the green space areas. However, in the past 70 years, new settlements have arisen throughout this southern sector (Graizbord & González Granillo, 2019). In the northern half, the vast majority of the 2,132 small scales (0.5-5ha) green areas are present, surrounded by the urban matrix. Even though there are thousands of small areas, these represent only 4% of the city's green space area (Table 1).

In NYC (figure 2b), there are 22 extra-large (>100ha) green spaces scattered over the landscape, not concentrated in one area; these represent 62% of the total green area. The majority (472) of green spaces are small in NYC, but they represent 7% of the total area (Table 1). The NYC extra-large green areas represent planning decisions based on geology (the land on the terminal moraine and the glacial outwash plain was low quality for agriculture and was subsequently used for parks such as Prospect, Green-wood, Forest, and Marine) and by political and social actions (e.g., Central and Van Cortland Parks) (Kieran, 1982; Schuberth, 1968). Political decisions reserved the smaller parks for local neighborhoods as the city grew from its original location in the southern tip of Manhattan.

The analyses based on our 500ha hexagon data sets catalog each cities' green space spatial characteristics help to evaluate the capacities of each city to keep habitat for native species and their dispersal capabilities. Frequency figures of each variable helped to compare green spaces presence, number, and distance in both cities' whole area (figure 3). The number (NumP) of green spaces appear to have a log-normal distribution. The number of smaller green spaces per hexagon is more common than large ones in both cities. On the contrary, the mean patch size (MPS) frequency figures are contrasting in both cities. While NYC has a large number of hexagons with small areas, and many fewer hexagons with larger areas, in MXC, the number of hexagons with different sized green spaces is almost constant.

Consequently, these findings relate to the distance between green space neighbors. When the number of spaces in a hexagon is greater, the distance must decrease. In NYC, the number of hexagons with different distances remains almost constant (MNN), and in MXC, most are concentrated at distances lower than 50m. This is expected since large areas covered by green space must have a small distance between them. The total green area (TCA) present within hexagons clarifies the difference between cities. Few hexagons are covered predominantly by green areas in NYC, but in MXC, the number of hexagons covered predominantly by green areas is large (figure 3). In NYC, there are almost no hexagons with green areas larger than 100ha, but in MXC, there are several hexagons with green space with this size. In NYC, most of the hexagons have less than 5% covered by green space and very few with a greater amount of green space coverage.

These frequency patterns suggest that NYC has a typical urban area distribution with a low area for green spaces, while MXC is a green city in which biodiversity has favorable habitat in most of the city's area. However, the spatial distribution of the green spaces in each of both cities reveals another story. Variance in MXC is extensive, and all the green spaces are concentrated in the south part of the city within protected areas (figure 4a). The number of patches per hexagon in MXC shows the predominance of small spaces in the southern part of dense urban area of the city's, in the middle of the region. In the northeast section, very few places were reserved for green spaces during urban planning decisions. The frequently encountered green spaces over short distances is within the mountainous and protected district at the bottom of the graph. The very bottom of figure 4a shows the impact of recent urbanization, which is fragmenting the original continuum of green space.

In contrast, many parts of the NYC landscape have few green spaces per hexagon (figure 4b). This is the result of large parks dominating some hexagons (such as Van Cortlandt in the Bronx and Marine and Prospect Park in Brooklyn) and other areas being devoid of green space planning during the urbanization of the early twentieth century. As illustrated in figure 2, the southern belt of Brooklyn and Queens are park-poor. Many small green spaces are concentrated in upper Manhattan and small sections of the Bronx and central Brooklyn.

Analysis of the mean patch size per hexagon (figure 5a) confirms that for MXC, the southern district has predominantly green space within most of the hexagonal units. However, the northern urbanized district almost completely lacks areas of large green spaces. The many green units here are relatively small, constraining their ecological community structure and ecological services. In NYC, hexagonal units with large mean green space sizes (figure 5b) are more regularly distributed across the landscape. The pattern of larger spaces forms almost continuous bands across large sections of each borough.

The nearest neighbor between any two green spaces helps to understand the potential for organisms' movement between the spaces in a city's layout. In MXC (figure 6a), most green spaces are close, <200m, from the next one across the entire landscape. This is caused by a large number of small green spaces in the northern section and the vast contiguous green space that predominates in the city's southern part. In contrast, in NYC (figure 6b), the lack of green spaces across Brooklyn and Queens, particularly (figure 2b), yields a pattern of relatively vast distances between adjacent green spaces. This would correlate with a more difficult movement of organisms between adjacent green spaces. Also, there is a band of more widely spaced green areas across the east-west center of the Brooklyn-Queens geography.

The total area covered by green spaces per hexagon shows a contrasting pattern between the cities (figures 7a and 7b). In Mexico City, there is a distinct green area reduction pattern from south to the northeast. However, in New York City, green areas in The Bronx, Queens, and Brooklyn are all significant, as well as Central Park in Manhattan.

Discussion

Ecological processes and the distribution of green spaces

These analyses can be interpreted as urban greenspaces being part of an "archipelago" of patches in a continuous ocean of infrastructure, susceptible to be colonized from relatively nearby parcels that are a reservoir of local biodiversity. Frequency analysis under this vision makes obvious the differences between cities. MXC functions as an archipelago of medium islands fed by a large green space in the south (=mainland), and a vast sea of buildings without any green space. NYC functions more like a small group of "mainland" centers with medium-size islands in an archipelago spread in the vast city territory. Island biogeography theory suggests these differences must have consequences in the distribution and survival capacities of species of both cities. The green "mainland" in both cities can harbor many species, including those whose niches require more area. The frequency analysis and the map suggest that the mainland at the south part of MXC is still capable to harbor most of the 83 native species of mammals (Guevara-López, Botello, & Aranda, 2016), particularly large ones such as the puma (Puma concolor), grey fox (Urocyon cinereoargenteus), deer (Odocoileus virginianus), teporingo rabbit (Romerolagus diazi), cacomixtle (Bassariscus sumichrasti), and opossum (Didelphis virginiana) (García, Lozano, Ortiz, & Monroy, 2014).

The data from NYC present several medium-sized "mainlands," capable of hosting many species (Gargiullo, 2007; Kieran, 1982). In NYC, green spaces are closely positioned to waterways such as Hudson and East Rivers, and Newark, New York, and Jamaica Bays. These have high biodiversity; Jamaica Bay is a vast wildlife preserve (Handel et al., 2016; Stalter & Lamont, 2002), and New York Harbor is the site of large-scale bird and fish migrations (U.S. Fish and Wildlife Service, 1997). These fringing habitats facilitate many plant and animal species dispersing and having access to the green spaces inland.

The distribution and size of green spaces modify their colonization capability, including barriers, such as highways, that must be navigated by species like big cats (Vickers et al., 2015). The number of green spaces in each hexagon of both cities is highly heterogeneous. Most green spaces have another green neighbor within 200m, although there are also many areas within 400m. However, in MXC, there are vast areas in the northeast

without any green space and consequently a reduced possibility of colonization. In NYC, there are two extensive infrastructure belts between Queens and Brooklyn that may reduce the migration from the south to the north there.

Both cities need planning for more hexagons with larger and closer green areas, particularly where they are lacking. This would be possible by increasing the number of areas that would increase habitat heterogeneity (Chang & Lee, 2016; Gaston, Ávila-Jiménez, & Edmondson, 2013). This is important in NYC, where there is no large mainland analogue, making smaller areas responsible for sustaining the city's diversity. High quality within an urban park, especially larger ones, is critical for biodiversity support.

The movement patterns of seeds are known from studies in open or forested areas (Howe & Smallwood, 1982). Dispersal patterns of species common in urban areas also are known. For example, oak (Quercus) species are common in New York and Mexico City. Oak seeds can be carried up to 2km by jays (Darley-Hill & Johnson, 1981). These broader movements help link tree populations widely separated across urban matrices (Lundberg, Andersson, Cleary, & Elmqvist, 2008; Lundberg & Moberg, 2003). However, the seed shadow is short, 15-20m, for most bird-dispersed species (Hoppes, 1988; Howe & Smallwood, 1982). A 2km distance would move a diaspore among many urban parcels in our study, but 20m would typically land on the pavement, not a recruitment site. There is wide variation for wind-dispersal plants, but most seeds fall close, less than 100m to the mother plant (e.g., Vittoz and Engler 2007). The less-common broadly dispersing seeds are critical for starting new populations and genetic mixing, but we have few studies of how tall and dense urban structures block movement. Human actions (fragmentation, logging) interfere with dispersal dynamics in non-urban areas, but the interplay may be even more intense in the built hurdles of cities (Markl et al., 2012).

Differences in urban dispersal capacities also occur for animals. Within NYC, movement and genetic relatedness studies of coyotes (Canis latrans) have shown rapid spread in very dense areas and that animals across many city parks are closely related (Henger et al., 2020; Nagy, Koestner, Clemente, & Weckel, 2016). In MXC, mammals such as cacomixtles and opossums are common in grey areas. The mammals use house roofs and trees to reach even small gardens, which become habitats.

Birds have greater dispersal capability than terrestrial organisms. Birds cross built areas in Sapporo at a high frequency; the urban matrix was not a barrier (Shimazaki et al., 2016), to reach the green spaces. In a broad review of birds and other taxa in urban parks (Nielsen, van den Bosch, Maruthaveeran, & van den Bosch, 2014b), the microhabitat heterogeneity and quality of habitat within the parks were most decisive in improving biodiversity. It is possible to watch herons, ducks, and coots flying to small 10m2 ponds in the south part of MXC, but rarely in the north (pers. obs.). Distribution and number of bird species in NYC are positively correlated with green space area, although the shape and isolation of patches were not significant to the number of bird species (La Sorte, Aronson, Lepczyk, & Horton, 2020). In MXC, the 355 recognized species of birds (Melendez-Herrera, Gómez de Silva, & Ortega-Álvarez, 2006) can share green spaces habitats regardless of their native, exotic or migratory condition (Ramírez-Cruz et al., 2019), but the diversity increases in areas where there is canopy (Ortega-Álvarez & MacGregor-Fors, 2009). This supports the conclusion that larger urban green spaces are essential for maintaining high bird biodiversity.

The invertebrate biodiversity is essential for urban food web structure. In NYC, bee species diversity in small urban gardens is significant, 54 species, although this is smaller than surveys in the larger NYC urban parks (Kevin C. Matteson, Ascher, & Langellotto, 2008). In MXC at least 269 species of bees have been identified (Cano-Santana & Romero-Mata, 2016). Bee diversity was also positively correlated with area of the plots and presence of wild, "unmanaged" plant species (Kevin C. Matteson & Langellotto, 2010), but floral resources and bee diversity varied across space and time in NYC and MXC vegetated urban areas (Domínguez-Alvarez & Cano-Santana, 2008; K. C. Matteson, Grace, & Minor, 2013). These studies are mirrored by other, wider insect studies in urban areas (Harrison & Winfree, 2015; Winfree, Bartomeus, & Cariveau, 2011). Small urban fragments have high insect β-diversity (Tscharntke, Steffan-Dewenter, Kruess, & Thies, 2002) with arthropods that respond positively to vegetated area, but patch isolation was less important (Turrini & Knop, 2015). Together these several insect-focused studies show that insect diversity can be high in urban centers and patch quality is important. Consequently, design improvements within parks may have significant value compared to purchasing new green spaces (Nielsen et al., 2014a).

Advancing ecological structure in urban planning

These two cities are old, where urbanization patterns reflect historical process. In both NYC and MXC, there is a clear pattern of areas with a substantial number of parks and other areas where fast urbanization, not always planned, did not consider or leave urban green areas. These hardscape areas generate landscape grey holes difficult for many species to cross. On the contrary, in both cities, some medium-size urban green spaces are related to historical processes within each city; that is the case for Central Park and the Brooklyn Botanical Garden in NYC and Chapultepec Park and Xochimilco in MXC. This shows the serendipitous way that cultural needs can support biodiversity concerns. Future urban planning initiatives can mirror this convergence by considering design decisions that advance the ecological needs as well as the social goals of a development (Le Roux et al., 2014).

To continue to rebuild our historical cities' design using these two goals, we need to understand which information, data sets, and institutional changes are needed. The spatial analyses we report illustrates base maps upon which biodiversity improvements can be molded. The quality of existing patches must be studied to determine what ecological improvements are feasible. Data on current biodiversity, movement, and practical ecological targets are needed to set priorities for ecological designers (e.g., Alvey 2006; Saura and Rubio 2010). Which species can survive in current, stressful urban conditions and with projected climate shifts? Which species can persist in existing spatial arrangements of green spaces and which will need some type of corridor, management change, or additional patches to maintain their population structure (e.g., (Angold et al., 2006; Threlfall, Williams, Hahs, & Livesley, 2016).

In addition to increasing the number of green spaces, new management concepts and training for existing green spaces may be needed to maintain or improve ecological function (Palazzo & Steiner, 2014). Our mapping of the green archipelago in these old cities is a quantitative start towards new design efforts to advance urban biodiversity and its many values. Work within historical cities can then be expanded for ecological improvements of regional metropolitan areas (Forman, 2008), as has been done for the NYC region (Flores, Pickett, Zipperer, & Poyat, 1998; Lewis, Nordenson, & Seavitt, 2019).

Cities are dynamic areas in which both structures and regulations can change in the future. The life span of a patch and addition of new habitats varies with local regulations and development pressures (Le Roux et al., 2014). Additionally, the economic factors important in urban design can be incorporated into decisions on ecological corridor construction and improvement (Peng, Zhao, & Liu, 2017). Because change in an urban green patch's presence or surroundings occurs regularly, species equilibrium may not always occur, a metapopulation effect. Green space bridges can assist sustainability in both cities. "Stepping stone" areas are of value (Ignatieva, Stewart, & Meurk, 2011; Andersson & Colding, 2014) in both cities and may be easier to create than continuous corridors. Ecological connections have been used in cities (LaPoint, Balkenhol, Hale, Sadler, & van der Ree, 2015), and these case studies can be a foundation for future plans in the cities analyzed here. The study's hexagons also help to prioritize paths for ecological restoration, for example, in the mentioned grey belts between Queens and Brooklyn in NYC and the North East area in MXC (Zambrano, Aronson, & Fernandez, 2019). These areas must be a priority for integrating green spaces by generating corridors for species to use, knowing that the behavior of the dispersers will determine the pattern and tempo of movement.

New rules and practices can be encouraged. For example, new architectural designs exist to add animal microhabitats into the facades of big buildings (Weisser & Hauck, 2017). Glass facades can be modified to be less dangerous to bird movements. "Green streets" can increase biodiversity movement (Mason, Moorman, Hess, & Sinclair, 2007), as well as increase engineering value (stormwater absorption, mitigation of heat). The spatial patterns of existing urban biodiversity are diverse (Rastandeh, Brown, & Pedersen Zari, 2017), and many different local solutions are possible.

Urban design decisions must include small-scale green spaces that accommodate to improve urban biodiversity, such as bioswales and infrastructure that comprise "green streets" (Beatley, 2017; Kemp, 2006). The known biodiversity in cities can be mirrored by a diversity of design decisions to break down the "grey-green dichotomy" that is the caricature of recent urban planning (Parker, 2015).

Historical cities' constraints challenge improvement of urban biodiversity. It is better to have an ecological presence in decision making early in planning and design (Dunnett & Hitchmough, 2004). New city designs may be a more accessible template upon which to create biodiverse urban centers. Patterns that will allow sustainability of urban biodiversity have been explored theoretically and by site analyses (e.g., (Beninde, Veith, & Hochkirch, 2015; Ikin, Knight, Lindenmayer, Fischer, & Manning, 2012; Markl et al., 2012; Weisser & Hauck, 2017). New conceptual areas for improving our efforts are continually being posed (Angold et al., 2006; Lepczyk et al., 2017; Müller, Werner, & Kelcey, 2010). There is a big opportunity to improve new urban spatial structures based on theoretical underpinnings from landscape ecology. Closer collaboration between ecologists and the design professions is paramount.

There are short-term actions to advance urban biodiversity, but our perspective must have a longer view, even in a time of rapid climate change (Nilon et al., 2017). Damschen et al. (2019) showed that biodiversity among reconnected habitat fragments increased after 18 years. The value of the connections still had not reached an asymptote. In both NYC and MXC, much of the array of green spaces have existed for well over a hundred years. This hexagon-based analysis supports decisions and policies for the addition of green areas with particular sizes, distances, and locations. New design decisions must demonstrate short term progress to

secure public and political approval, but the ecological time scale of change is long and must outweigh the typical emphasis on annual or short-term goals.

Declarations

Acknowledgments

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Tables

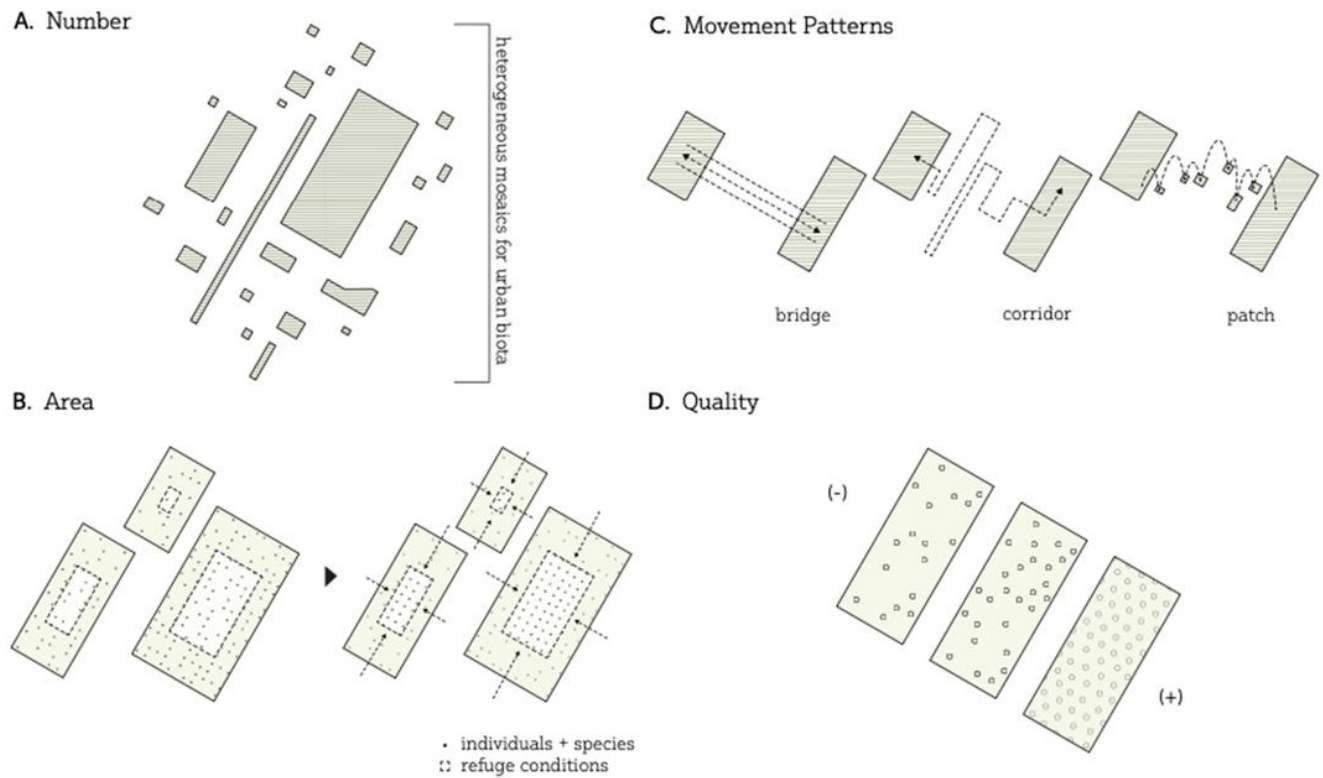| Table 1. Number and area occupied by urban green spaces in both cities.				
MXC				
Size	FREQUENCY	%	HECTARES	%
0.5-5 ha	2132	89	2,900	4
5.1-25 ha.	210	9	2,026	3
25.1-100 ha	32	1	1,566	2
larger than 100 ha	17	1	65,685	91
Total	**2391**	**100**	**72,177**	**100**
NYC				
Size	FREQUENCY	%	HECTARES	%
0.5-5 ha	472	76	641	7
5.1-25 ha.	88	14	1,044	11
25.1-100 ha	36	6	1,914	20
larger than 100 ha	22	4	5,909	62
Total	**618**	**100**	**9,508**	**100**

Figures

Figure 1

Spatial characteristics of green areas that affect biotic communities in cities. A) Number of green spaces within an urban area. B) Area occupied by green spaces, which may increase the habitat for species. C) Quality of green spaces, which modifies the number of habitats for species. D) Distribution of green spaces, which modify the possibilities of dispersion of the specie by green bridges, corridors or patches.
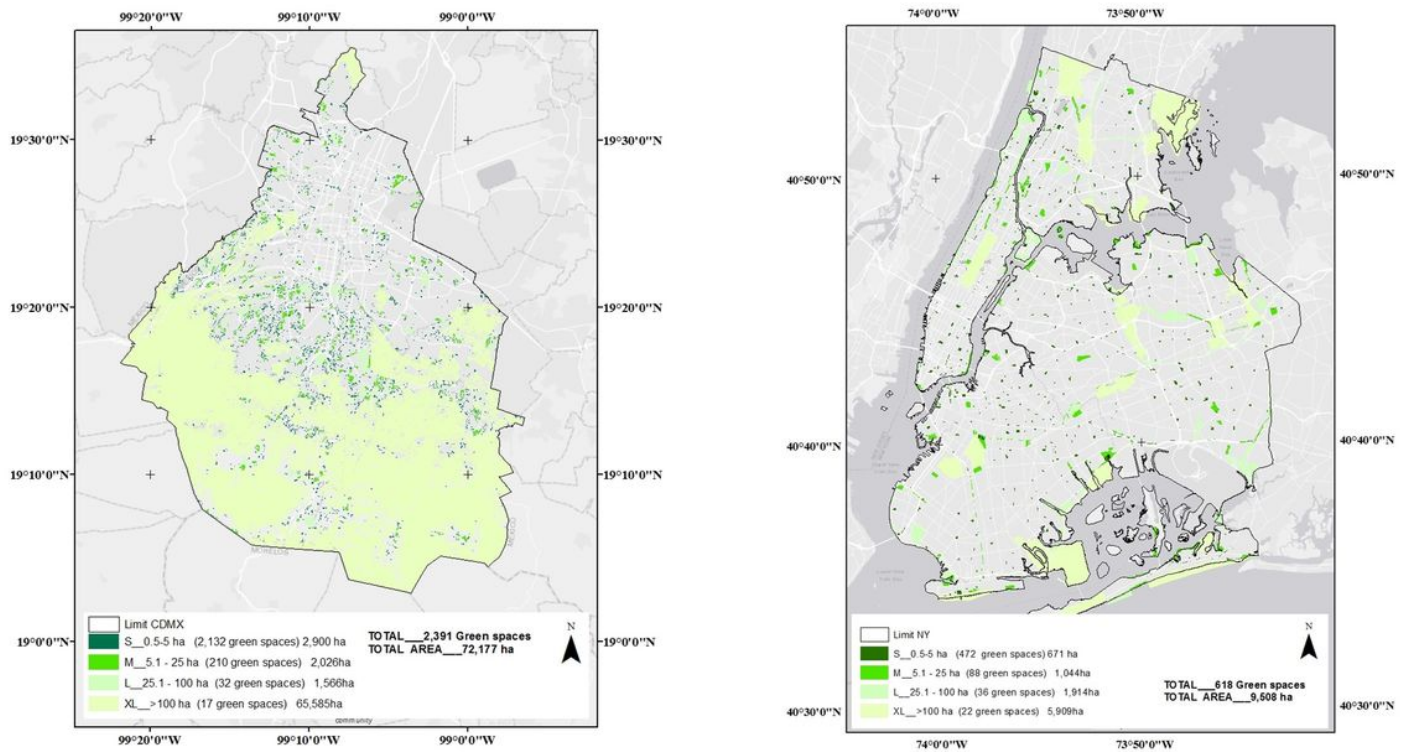
Figure 2

Mexico City (a) and New York City (b) green spaces maps. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
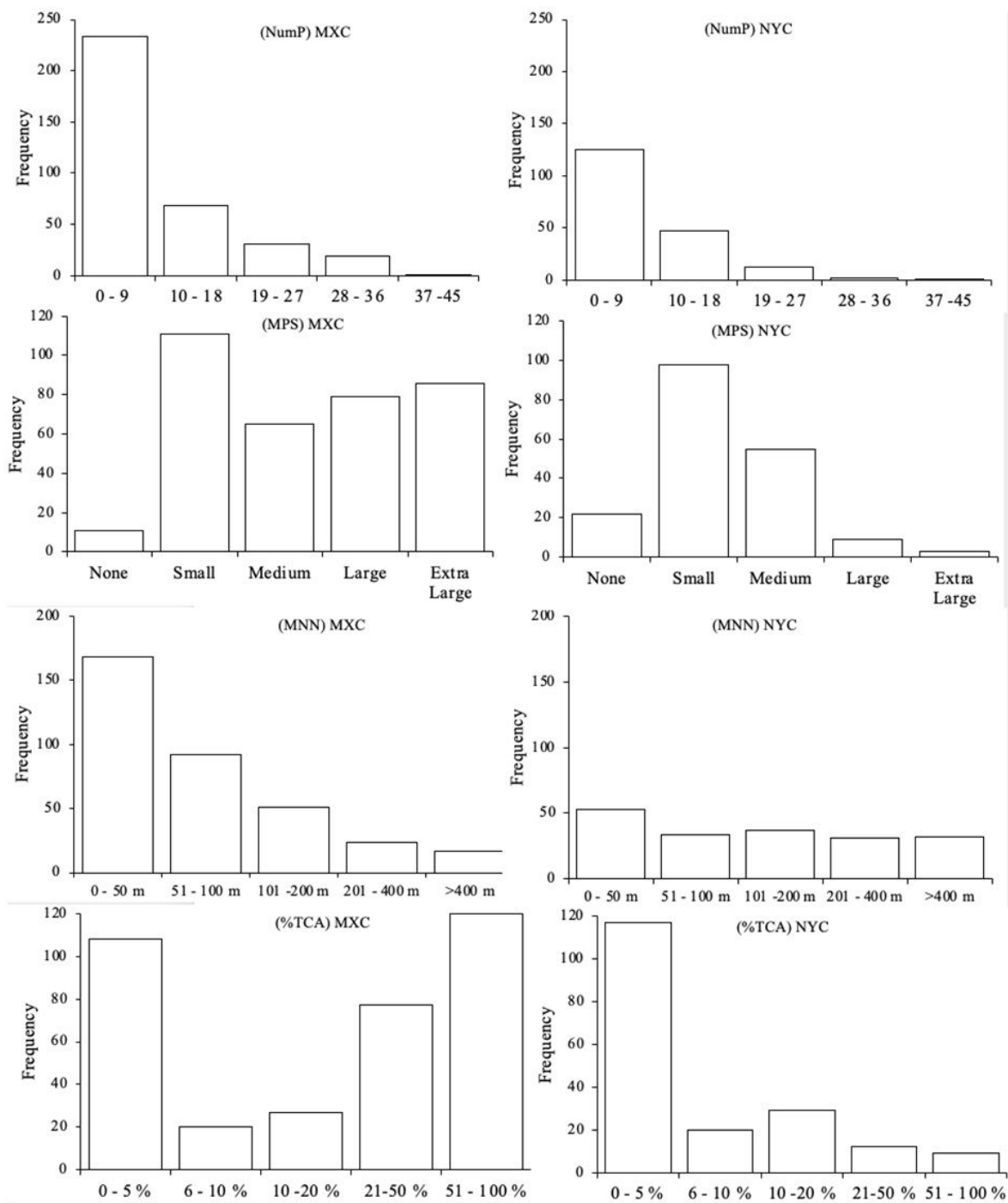
Figure 3

Frequency analysis considering categories of each variable NumP = Number of green spaces within each hexagon; MPS = Mean patch (green space) size of each hexagon; MNN = mean nearest neighbor between green spaces; and %TCA = Percentage of total core (green) area of each hexagon. MXC = Mexico City and NYC = New York City.
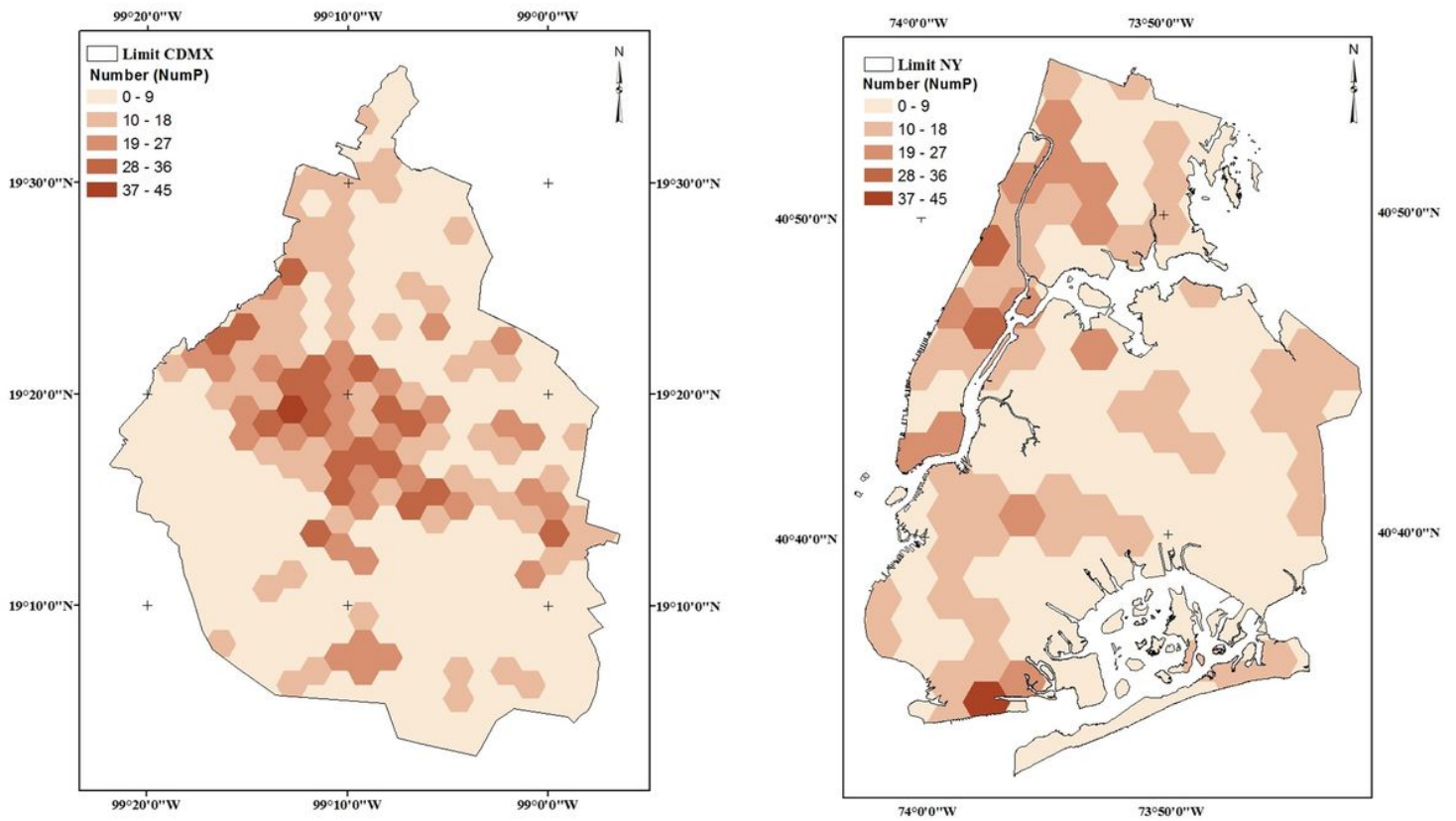
Figure 4

Number of green spaces per hexagon (NumP) in Mexico City (a) and New York City (b) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
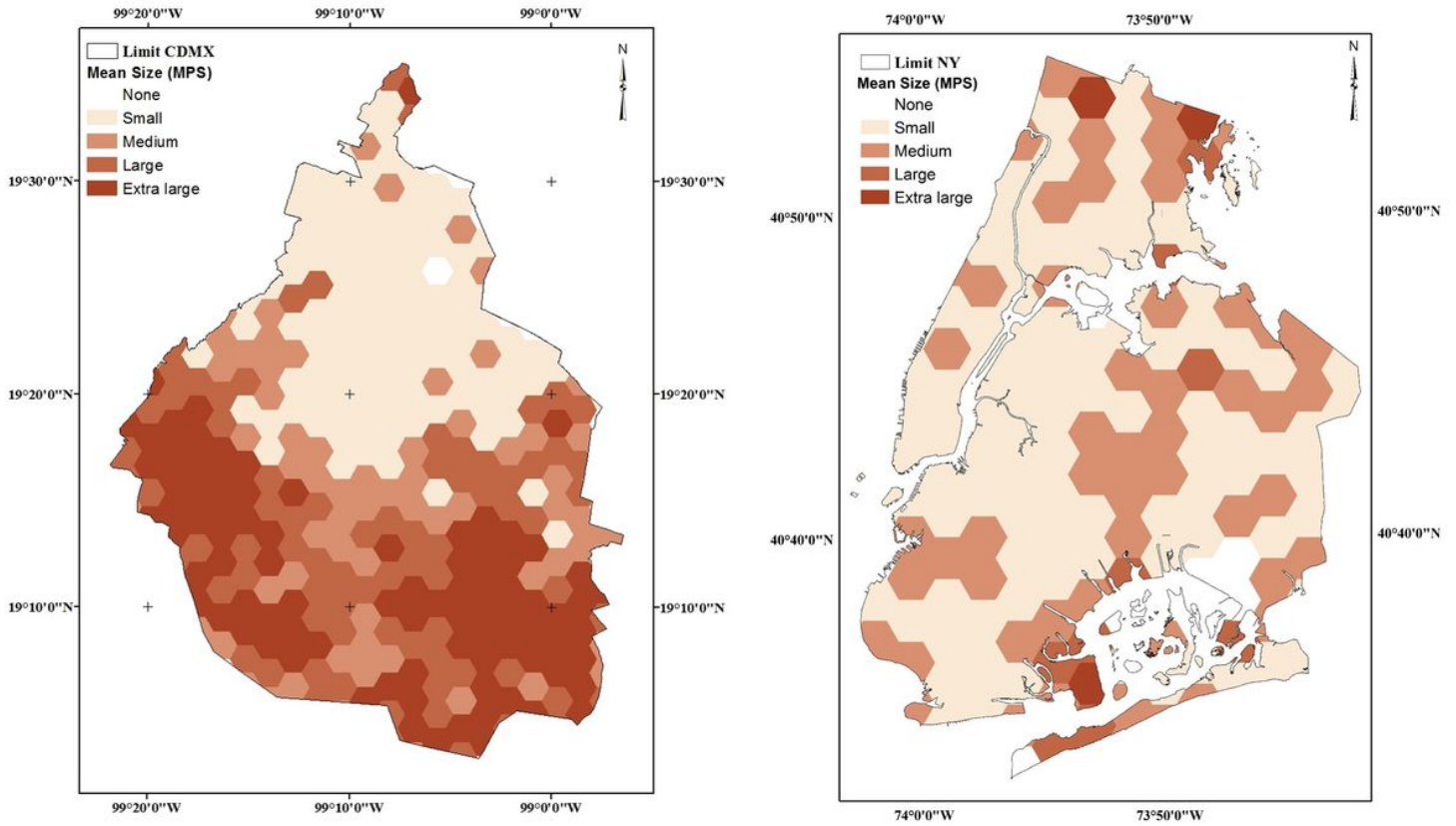
Figure 5

Mean green space size on each hexagon (MPS) in Mexico City (a) and New York City (b) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
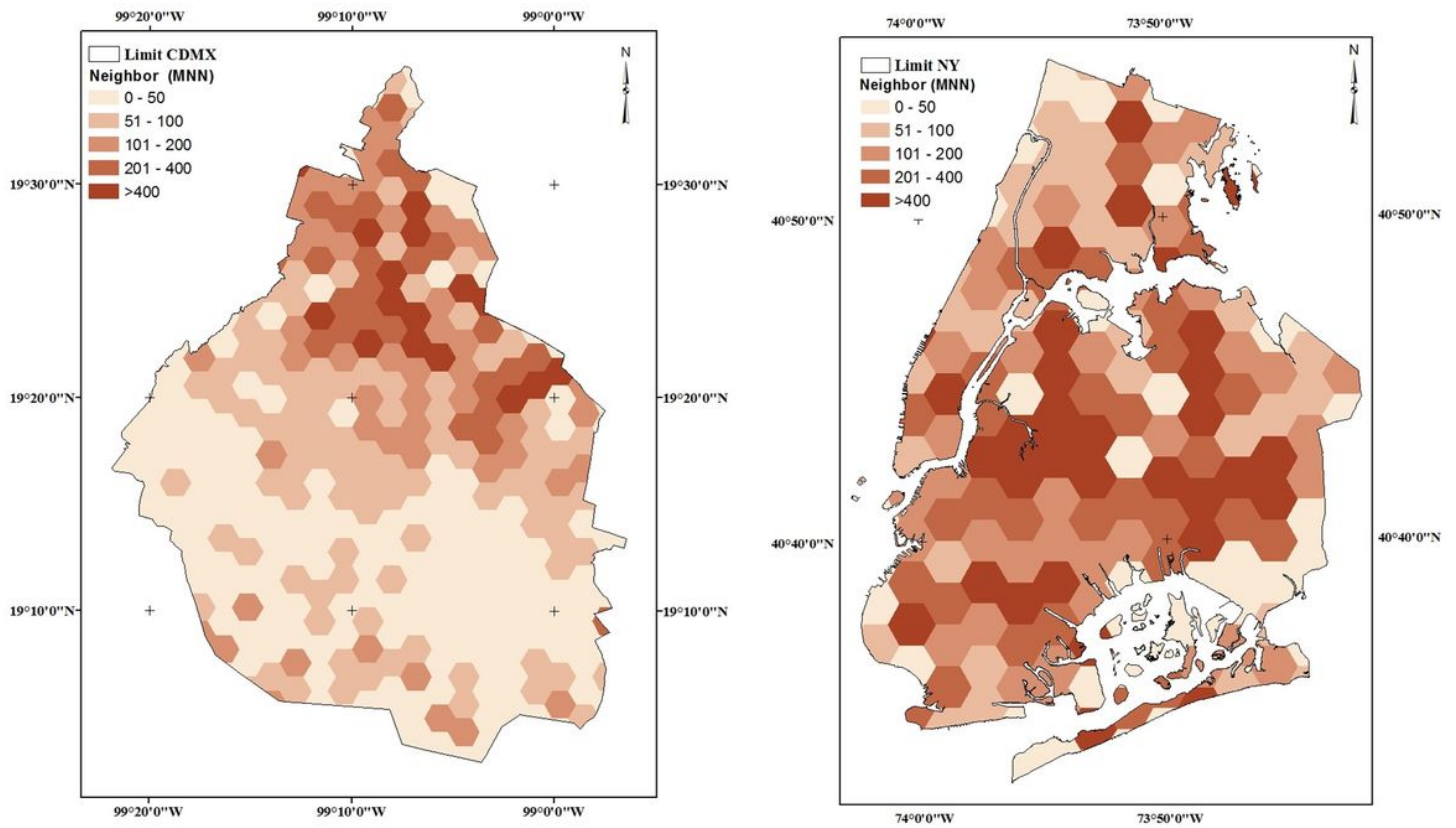
Figure 6

Mean nearest green space neighbor (MNN) on each hexagon in Mexico City (a) and New York City (b) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
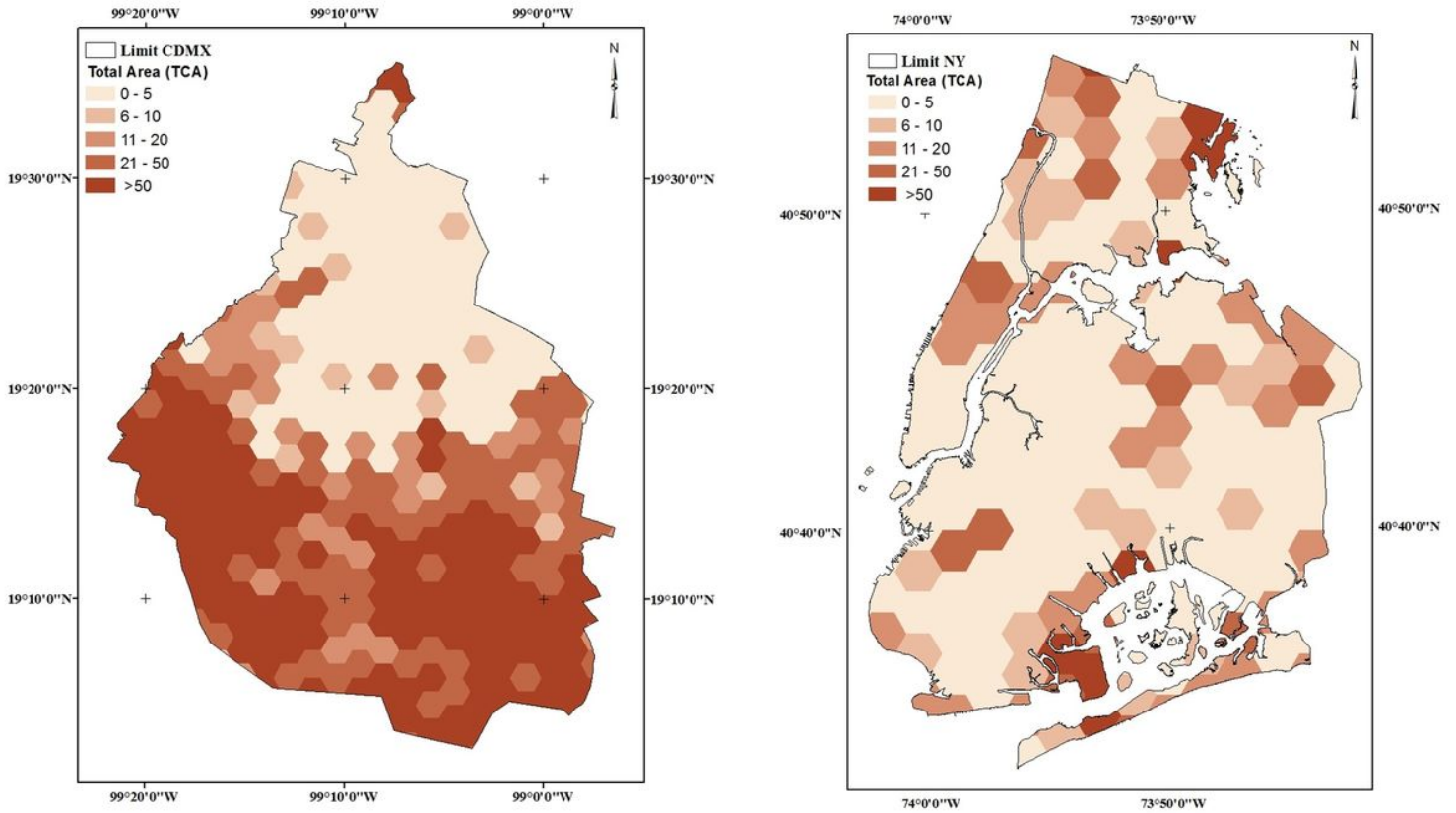
Figure 7

Percentage of Total area covered area by green spaces (%TCA) on each hexagon in Mexico City (a) and New York City (b) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.