Increased access to nearby green–blue areas associated with greater metropolitan population well-being

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Abstract
Numerous cities in the world have to handle and support increasing populations, with questions remaining concerning good planning strategies for their growth and development. Among these questions, access to nature for urban residents has been the subject of increased scrutiny in recent years. We here propose and apply a generally applicable new approach to quantitatively investigate the role of close access to natural or nature-based green–blue areas for the well-being of urban populations. A key novel aspect of this approach is to use income level as a measure of people's ability to choose their nearby living environment such that it provides them with the highest affordable level of well-being. Based on this measure, we concretely investigate possible trends in local green–blue area access with increasing local income level in the case-study example of the Stockholm Metropolitan region in Sweden. For this regional case, we find clear relationships between income level (and related degree of nationality homogeneity) and share of natural/nature-based green–blue areas and man-made grey areas within walksheds of different population segments. The results point at the importance of maintaining and restoring nearby natural and nature-based green–blue areas as key solutions for increased well-being of urban populations and call for further testing and comparative investigations of local-scale associations between socio-economic descriptors and physical environment in other parts of the world.

Keywords
green–blue urban areas, nature-based solutions, socio-economic conditions, spatial accessibility, urban and peri-urban Stockholm region

1 | INTRODUCTION
Cities are now home to the largest share of the global population in recorded history, with an estimated 54% of the total global population being urban dwellers. The shift from rural to urban living is a relatively recent change (30% of the population was considered urban in 1950), projected to continue into the future, possibly reaching 66% of the global population by 2050 (United Nations Population Division, 2014). In Sweden, for example, close to 85% of the population already live in urban areas (United Nations Population Division, 2014).

Theories on how cities function as complex systems are still at their beginning, but recent work suggests that certain scaling laws and patterns emerge from urban conditions (Batty, 2008). Many urban indicators follow power law functions, scaling sublinearly, linearly, or superlinearly with city size, even though the universality of such functions is still debated (Arcaute et al., 2015; Bettencourt, 2013; Bettencourt, Lobo,
Helbing, Kühnert, & West, 2007; Cottineau, Hatna, Arcaute, & Batty, 2017). Comprehensive tackling of sustainable development challenges requires interdisciplinarity and integrated theories, methods, and approaches at the interface between social and ecological systems (Bettencourt & Kaur, 2011; McPhearson et al., 2016; McPhearson, Haase, Kabisch, & Gern, 2016; Seto, Golden, Alberti, & Turner, 2017), with quantitative city analytics contributing to such efforts by providing new opportunities and insights into urban systems and urban life (Higham, Batty, Bettencourt, Greetham, & Grindrod, 2017).

Among these concerns, access to nature for urban residents has been the subject of increased scrutiny in recent years, as this access is restricted in urban settings and the ‘correct amount of nature’ for sustainable urban life is unclear (Richardson et al., 2012; Shanahan, Fuller, Bush, Lin, & Gaston, 2015; Turner, Nakamura, & Dinetti, 2004; Wolch, Byrne, & Newell, 2014). Green areas, defined as open land with natural vegetation, and blue, water-covered, areas, such as wetlands, can provide environmental benefits and nature-based solutions to at least some urban problems (Bolund & Hunhammar, 1999; Gómez-Baggethun et al., 2013; Keesstra et al., 2018; Thorslund et al., 2017). For example, such green-blue areas can serve as social and recreational areas for urban residents (Bjerke, Østdahl, Thane, & Strumse, 2006; Burgess, Harrison, & Limb, 1988), as well as attenuate storm water (Dietz & Clausen, 2005; Goldenberg et al., 2017) and mitigate urban heat island effects (Buyantuyev & Wu, 2010; Goldenberg et al., 2017; Jenrette et al., 2007; Rizwan, Dennis, & Chunho, 2008).

Several studies have promoted the view that green space in urban settings provides beneficial health effects, although direct causal relationships are difficult to establish (Lee & Maheswaran, 2011; Tzoulas et al., 2007). Nevertheless, green space provides opportunities for physical activity (McCormack, Rock, Toohey, & Hignell, 2010; Richardson, Pearce, Mitchell, & Kingham, 2013; Salis et al., 2016), psychological well-being, and stress reduction (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Nutsford, Pearson, & Kingham, 2013; Thompson et al., 2012). There is also moderate evidence of positive relationships between self-reported health and green space in the living environment (De Vries, Verheij, Groenewegen, & Spreeuw, 2003; Maas, Verheij, Groenewegen, De Vries, & Spreeuw, 2006; van den Berg et al., 2015). Populations that are exposed to greener living environments also tend to experience lower levels of income-related health inequality (Mitchell & Popham, 2008). Furthermore, the UN global sustainable development goal 11, on sustainable cities and communities, includes provision to ‘universal access to safe, inclusive and accessible, green and public spaces’ by 2030 (UN General Assembly, 2015).

Access to green-blue areas and the nature-based solutions that they can provide is also an issue of environmental justice or equity (Jennings, Johnson Gaither, & Gragg, 2012; Pearsall & Pierce, 2010). Some studies have started to examine how societal characteristics of a population (personal income, ethnicity, and religion) relate to such access (Barbosa et al., 2007; Comber, Brunsdon, & Green, 2008; Jenrette et al., 2007; Landry & Chakraborty, 2009; Schwarz et al., 2015). However, the variety of used methods and considered problem scales and accessibility measures make direct study comparisons difficult and may lead to apparent conflicting results (Ekkel & de Vries, 2017; La Rosa, 2014; Tan & Samsudin, 2017). In this study, we develop a generally applicable new approach to quantitatively investigate how access to natural or nature-based green-blue areas covaries with local socio-economic conditions at various locations of residence of a metropolitan population. A key novel aspect of this approach is to use the income level of the population segment at each location as a measure of people’s possibility to choose their nearby living environment such that it provides them with the highest affordable level of well-being. Quantitative results of the approach, in terms of possible trends in local green-blue area access with increasing local income level, can be compared across regional cases, leading to wider and more general understanding of the role of such natural/nature-based areas for the well-being of urban populations. For concrete case study application and quantification of this approach, we use here the large (area-wise) and varying (in terms of land cover) Stockholm Metropolitan region in Sweden.

In particular, we investigate and quantify for this regional case example the residential proximity relationship to natural and nature-based green-blue land-cover areas and for direct comparison also to grey, man-made, urban land-cover areas. We use a regular spatial grid to determine this relationship in terms of a local ‘walkshed,’ based on access (walking travel) time in the prevailing street/road network and aggregate socio-economic data along with road and land-cover data at this local scale, independently of administrative delineations. Thus, for each locality, represented by the central point of each hexagon in the regular grid, we ask and quantitatively answer the following two questions:

1. What is the socio-economic background (population count/density, yearly income, and nationality) of people living in the vicinity of this locality?
2. What land-cover conditions compose the nearby living environment of these people (reached by <10-min walking)?

Considering all the local data points over the whole Stockholm region, we further ask and quantify the answer to the following overarching question:

3. How do the socio-economic conditions of different segments of the regional population covary with the land-cover characteristics (natural/nature-based green-blue areas and grey areas) in their nearby living environment?

2 MATERIAL AND METHODS

2.1 Study region

The studied Greater Stockholm, or Stockholm Metropolitan region (Figure 1), is located in northern Europe; includes the capital city of Sweden, Stockholm; and covers roughly 6,500 km² of land surface. In 2016, approximately 936,000 people lived in the Stockholm municipality, and 2,269,000 lived people in the whole Greater Stockholm region (Statistics Sweden, http://www.scb.se). The region includes numerous islands in Stockholm city and on the eastern coast (with the islands located east of Stockholm in the Baltic Sea forming the Stockholm archipelago) and represents a boreo-nemoral biome (Elmhagen et al., 2015), with long-term (1961–1990) average annual rainfall of
539 mm (472 mm in 2016) and temperature of 6.6°C (8.2°C in 2016) (data source: Swedish Meteorological and Hydrological Institute, http://www.smhi.se). The region also includes a large share of green–blue areas compared with other urban regions in Europe (Fuller & Gaston, 2009; Kabisch, Strohbach, Haase, & Kronenberg, 2016), also within or close to its main urban areas and even though its green structure has been increasingly fragmented in recent years due to increasing population and urban expansion (Colding, 2013; Elmqvist et al., 2004).

2.2 | Data and methods

General information on all datasets used in the study is listed in Table 1. The land-cover data are based on the European Urban Atlas (Montero, Van Wolvelaer, & Garzón, 2014) and the Continuous Habitat Type Mapping of the Swedish Environmental Protection Agency (SEPA, 2004). We use both datasets because the European Urban Atlas provides excellent classification and resolution of urbanized areas, while the SEPA provides more data on forests and other natural areas. The original data for Stockholm from the European Urban Atlas are converted to a 10 m resolution raster before being combined with the SEPA data.

A regional dataset for normalized difference vegetation index (NDVI) is compiled from the MODIS (Moderate Resolution Imaging Spectroradiometer) Vegetation Index data for the Aqua and Terra satellites (Didan, 2015a; Didan, 2015b). Three 16-day time slices are gathered from each satellite, covering approximately the same temporal extent (June 2 to July 20, 2015, for Aqua and June 10 to July 28, 2015, for Terra). These time slices are first combined based on satellite provenance by calculating the mean pixel value for each triplet of data. The resulting two NDVI data slices (representing the mean NDVI value over the periods considered for each satellite) are further aggregated by keeping the maximum pixel value between them.

Road data are obtained by extracting road network shapefiles and create a routing network for the whole region using the ArcGIS Editor for the data source (Open Street Map, 2016). The resulting network is first automatically and further manually cleaned to remove faulty road segments and connections and adapted to simulate pedestrian walking.

![FIGURE 1](http://wileyonlinelibrary.com) Location of the study area, the Stockholm Metropolitan region [Colour figure can be viewed at wileyonlinelibrary.com]

### TABLE 1 General description of the datasets used in the present study

| Name (original name) | File type | Resolution | Temporal reference | Institute |
|----------------------|-----------|------------|--------------------|-----------|
| Population count (B2_GRID) | Grid shapefile | 250 m in urban areas, 1 km in rural areas | 2013 | SCB (Statistics Sweden) |
| Median yearly income (IF1_GRID) | Grid shapefile | 250 m in urban areas, 1 km in rural areas | 2012 | SCB |
| Nationality (B5_GRID) | Grid shapefile | 250 m in urban areas, 1 km in rural areas | 2013 | SCB |
| Land cover (Urban Atlas) | Shapefile | Geometric resolution: 0.25 ha, Positional accuracy: ±5 m | 2006 | EEA (European Environment Agency) |
| Continuous Habitat Type Mapping (Kontinuerlig Naturtypskartering) | Raster | 25 m | 2004 | SEPA (Swedish Environmental Protection Agency) |
| NDVI (MYD13Q1-MODIS/AQUA Vegetation Indices 16-Day L3 Global 250 m SIN Grid V006) | Raster | 250 m | June 2, 2015 to July 20, 2015 (3 × 16 days) | NASA EOSDIS Land Processes DAAC |
| NDVI (MOD13Q1-MODIS/TERRA Vegetation Indices 16-Day L3 Global 250 m SIN Grid V006) | Raster | 250 m | June 10, 2015 to July 28, 2015 (3 × 16 days) | NASA EOSDIS Land Processes DAAC |
| Road Network | Shapefile | 2016 | OSM (OpenStreetMap) |

Note. DAAC: Distributed Active Archive Center; NASA EOSDIS: National Aeronautics and Space Administration Earth Observing System Data and Information System; NDVI: normalized difference vegetation index; MODIS: Moderate Resolution Imaging Spectroradiometer.
conditions. All road segments inaccessible by foot (such as highways) are defined as such in the dataset, and the travel speed used for all road segments is an average human walking speed of 5 km/hr.

The socio-economic data, including population count, median yearly income (for families 20+ years total earned income) and nationality, are assembled (from Statistics Sweden, 2012–2013) on a regular hexagonal grid with a side length of 75 m (representing an approximate area of 1.46 hectares per hexagon). Each original dataset is recalculated on this grid using an area-weighted mean data value $x_i$ for each hexagon $i$, as

$$x_i = \frac{\sum_{j=1}^{n} (x_j \times A_j)}{\sum_{j=1}^{n} A_j}$$

Where: $x_j$ is a value from the original dataset and $A_j$ is the corresponding value support scale within hexagon $i$. A unique identifying number is attributed to the center point of each hexagon, which is also used as the departing point for the walking time calculations that define a walkshed (Figure 2).

Specifically, a walkshed is defined as the surface area accessible by walking 10 min in any particular direction along the road network, starting from the center point of each hexagon cell unit. For this reason, choosing a relatively detailed grid (75-m side length hexagons, meaning approximately 130-m distance between two neighboring center points) is important for mitigating routing errors and obtaining appropriate walksheds. The grid needs to provide relevant representations of roads and socio-economic conditions, as well as of the accessible land-cover conditions for most (ideally all) people within the associated walksheds. For example, a coarser grid cell may contain a physical obstruction (natural or human) close to its center point, implying different routing patterns on either barrier side, the averaging of which may not appropriately represent conditions on any side. Walksheds are further calculated from each center point of populated grid cells and used to aggregate the (share of each class of) land-cover and the average NDVI value within the walkshed area.

A graphical explanation of the methods used in the study is provided in Figure 2, illustrating a sample subset of the region and one sample center point. Each final data point is associated with the socio-economic data aggregated over its corresponding unit hexagon and to the road network and land-cover shares contained in its corresponding walkshed.

Due to the varying resolution of socio-economic data, we select data points (i.e., hexagon center points) with population counts $\geq 2$. For some rural zones with low population and housing densities, the original statistics are averaged over 1 km$^2$. Otherwise, it would be difficult to apply appropriate statistics to these zones and many inaccurate data points would skew the results. Moreover, we consider a total range of median yearly income of SEK 50,000–1,200,000, in order to have a minimum number of data points in each income segment within this range. The study region includes approximately 49,000 data points and associated hexagon units and walksheds with population and income distribution as shown in Figure 3, and with a wide variety of different urban and peri-urban land-cover and socio-economic conditions. By use of this data coverage, the purpose is to identify possible covariation between the socio-economic conditions and the access to green–blue and grey areas of people living in the study region. We have used the ArcGIS software environment (ESRI, 2011) to process the spatial data and perform the road network and

![Figure 2](Colour figure can be viewed at wileyonlinelibrary.com)
routing calculations, and we have analyzed the results using the Python programming language (Python Software Foundation, 2017).

3 | RESULTS

The result graphs in Figures 4–9 show box plots with the whiskers displaying the 5th and 95th percentiles, and the boxes displaying the first quartile, median and third quartile, for each median income segment. Thus, 90% of the data points are contained between the two whiskers and 50% in the box. The dotted light blue line in each graph links mean values, while the dark blue line links median values, for different income segments (Figures 4–7) or non-EEA (European Economic Area) nationality proportions (Figures 8 and 9) in the regional population. Land-cover results are illustrated for the different following land-cover features (categories): areas with different urban density (>30% and ≤30% soil sealing), infrastructure in terms of industrial-commercial and sport-leisure-facility areas, and natural/nature-based green areas (in terms of parks, forests and NDVI) and blue areas (water covered). The underlying statistics for the relative area of each land-cover feature, as presented below, are further shown in Table SA, and associated maps for principal clusters of high and low income/EEA population proportions in the region are provided in Figure SC.

3.1 | Urban areas

In the original land-cover database, different urban subclasses are categorized in terms of soil surface share sealed by artificial surfaces. In this study, we have identified a distinctly different covariation behavior for >30% soil sealing (high density urban; Figure 4A) than that for ≤30% soil sealing (low-density urban; Figure 4B). Overall, the average share of high-density urban zones is highest (mean around 12–19%) in the walksheds of people with relatively low income (SEK 50–350 · 10³); the spread in the area share of these zones is also relatively high in the low-income range. For low-density urban zones, their average area share increases in the walksheds of people with increasing income up to around SEK 900 · 10³, reaching a plateau at a mean value of around 40% for people with even higher income.

For people with higher income, and thereby greater possibilities to freely choose their living conditions, there is thus a clear preference for larger average share (up to 40%) of low-density urban zones within their walksheds. Such low-density urban zones do likely also contain a relatively large share of greenery (such as gardens and small forest patches) in between their sealed soil area of <30%.
3.2 | Man-made infrastructure

The land-cover class of industrial and commercial zones (Figure 5A) includes zones with a minimum of 30% sealed soil, and 50% of the artificial surfaces occupied by nonresidential (industrial, commercial, public, military or private) buildings and structures. The class of sport and leisure facilities (Figure 5B) includes all features identified as such, whether on nonsealed or sealed soil, or built-up surfaces.

As for the high-density urban zones (Figure 4A), the average area share of industrial and commercial zones decreases in the walksheds of people with higher income, from around 15–20% for the lowest income levels (SEK 50–100 · 10^3) to around 2%–3% for the highest income levels (SEK ≥ 1000 · 10^3) (Figure 5A). Industrial and commercial zones are thus strongly avoided by the richer parts of the population, who can more freely than poorer people choose their preferred living conditions. Regarding the class of sport and leisure facilities, they cover on average only a small area share (<1%) and there is no apparent preference for this increasing or decreasing in the walksheds of people with higher income (Figure 5B).

3.3 | Green areas

We consider here the land-cover categories of (coniferous, deciduous and/or mixed) forest areas (within or outside urban zones) and parks that may include urban green areas and/or patches of seminatural grassland in more rural and/or recreational parts of the region; small forested zones in the latter parts are classified separately and added to the former, forest, category. As an alternative measure of green areas, we also calculate the area-weighted average NDVI value, representing the average density of vegetation, in each walkshed and compare results with those for the forest and park land covers.
Results for forest zones (Figure 6A) exhibit an inverse co-variation and preference behavior with increasing income as that for high urban density zones (Figure 4A). Overall, the average share of forest zones is lowest (mean around 15%) in the walksheds of people with relatively low income (SEK 50–350 · 10^3). Over the income range SEK 350–500 · 10^3, there is a sharp rise in the average share of forest zones, and for even higher income levels this share stabilizes at around 21–23% (Figure 6A). There is relatively large variation around the mean, but the bottom whiskers are almost always above zero, meaning that 90% of the population has at least some access to nearby forests (even if with a small area share) in the study region.

Results for parks show a relatively stable average area share (around 7%–10%) across the various income levels, even though the highest shares are found for the lowest incomes (Figure 6B). Other studies have reported results for parks pointing in the other direction (e.g., Wolch, Wilson, & Fehrenbach, 2005; Boone, Buckley, Grove, & Sister, 2009; Wen, Zhang, Harris, Holt, & Croft, 2013 or Mavoa et al., 2015). In the Stockholm region, the common access to at least some nearby forest area for people across all income levels (Figure 6A) may be a reason why parks are not as valued here (not primarily preferred by people with high income) as they may be in other regions.

The NDVI results (Figure 6C) further show similar covariation and preference behavior with increasing income as that for forests: the right-hand inset in Figure 6C also shows the calculated mean NDVI value over the region (with one standard deviation error bars) for all land-cover features discussed above. The period represented by the NDVI data (June–July) corresponds roughly to the peak growing season for most of the deciduous vegetation in the region. Mean NDVI values are the smallest, around 0.62–0.63, for the lower end of the income range (SEK 50–350 · 10^3), increasing to around 0.71 over the income range SEK 350–500 · 10^3, and remain stable at that level for even higher incomes: the spread around the mean is also larger for lower incomes and decreases for incomes >SEK 500 · 10^3. The average NDVI value for higher income levels corresponds to that characterizing the low-density urban zones. This is consistent with the finding for the latter that people with higher incomes prefer a relatively large average share of low-density urban zones within their walksheds; the relatively high characteristic average NDVI value for these zones also shows that there is considerable greenery in between their <30% sealed soil parts.

3.4 | Blue areas

For the category of water-covered, blue areas (Figure 7), we do not distinguish between fresh and brackish water. In a walkshed, such areas are also reached by walking paths along a shore and the question of what is the blue area share within the walkshed becomes fuzzy. For this category, we therefore also consider circles with a 400-m radius, centered at each data point, as an accessibility measure. The radius measure represents approximately half the distance a person can walk in 10 min, and we use as representative average blue area share the maximum value obtained between this and the general walkshed share measure.

Overall, the average share of blue areas increases with increasing average income level in the walksheds (or 400-m radius circles), from around 3% for the lowest to around 12% for the highest level. Greater shares of water-covered, blue areas are thus sought in the surroundings of people with a greater freedom of choice, as provided by their higher income level.

3.5 | Nationality

Figure 8 shows the relationship between average income level and nationality, where the latter is quantified in terms of 5% increment segments of the ratio of non-EEA to EEA citizens living in each grid cell. A low ratio means a homogeneous population of mainly EEA citizens, while a higher ratio means a more diverse with a higher non-EEA population share. There is a clear negative relationship of lower income with increasing population diversity in the study region. For example, the mean income in locations with 50% non-EEA population is approximately one third of the income of the most homogeneous population class (with 95–100% EEA citizens).

The found relationship between income and nationality also has implications for the living environment of more heterogeneous versus that of more homogeneous population locations. In particular, the least desirable walkshed conditions for people with higher income, who can more freely choose where to live, are characterized by large area shares of high-density urban zones and industrial and commercial zones. Increasing population diversity (and associated lower average income level) is then clearly associated with higher area shares of these particularly undesirable conditions (Figure 9), which also have the overall lowest vegetation densities as measured by their characteristic average NDVI values (see right hand insert in Figure 6C). These findings show that the ethnically more homogeneous parts of the regional population do not only have higher incomes but also greater access to nearby natural/nature-based green (and blue) areas in their surrounding walksheds.

4 | DISCUSSION

Stockholm is one of the greenest cities in Europe (Fuller & Gaston, 2009; Kabisch et al., 2016), including also large water areas within and along the extensive coastline of this metropolitan region. Moreover, Swedish governments have since long emphasized the importance of natural areas in urban planning for Swedish cities (Sandström 2002). Recognizing this exceptional situation, we show that intraregional variations in living environment conditions are nonetheless present, with the presence of green–blue areas in particular depending on local socio-economic conditions. Thus, by being rarer, such green–blue areas could be even more valued and desirable in other European metropolitan areas, in particular due to lower average green space coverage at the city scale (Fuller & Gaston, 2009). However, more investigations in other regions, using the quantification method developed in this study, would be needed to clarify this aspect.

Methodological choices made for the present study are important for different reasons. First, we used data on a fine scale to be able to capture the local socio-economic and landscape variability, with walksheds and data points aggregating information at different scales.
Second, we selected populated data points in the whole Stockholm region to refrain from using arbitrary delineations or some specific definition of a city. Using a different, administrative delineation instead would mean varying scale units within the region, with the aggregation of data and scale of analysis geographically bound to the same administrative units, or simply to a coarser resolution that would obscure local variability (Tan & Samsudin, 2017). Moreover, administrative boundaries represent a discretization of the landscape that is rather subjective or political in nature, with resulting calculated metrics arbitrarily dependent on the extent of these boundaries. For example, Fuller and Gaston (2009) suggest in their study that green space provision is primarily related to city area. Depending on the definition of an urban boundary, results could thus differ significantly (Cottineau et al., 2017). Also, using network distances requires more data and is more computer-intensive. Moreover, considering physical (natural or anthropogenic) barriers to movement provides more precise and accurate results than using buffers and Euclidean distances (La Rosa, 2014), and even more so for a landscape as fragmented as the Stockholm region.

Another important and potentially novel aspect of this study (to the best of our knowledge) is that we measure the percentage (or amount) of nature-based green and blue areas in the local environment and also try to encompass the different forms that these features might take, but also considering other, man-made grey land-cover types (the latter generally appearing to be undesirable). Low-density urban areas (containing street scale greenery, such as gardens), as well as forests, lakes, sea and parks, all form an important aspect of human contact with nature in an urban setting. These may fulfill different types of uses and offer different solutions depending on population needs and opportunities. In particular, a majority of the greenery in low-density urban areas is likely to be private, whereas parks are public. Measures of vegetation density (NDVI), while less discriminative in terms of types of features, also provide a useful indication of a general ‘greenness’ of the surrounding environment. Recent studies tend to suggest that more consistent and positive associations with health indicators (and thus well-being) are generally found depending on the surrounding amount of natural areas, rather than just their proximity (Ekkel & de Vries, 2017; Triguero-Mas et al., 2015). In the present study, we used income as a proxy for the possibilities of choice of living environment, assuming the relation with well-being to be dependent on this possibility for a person to realize his/her individual choices. An important extension of the present work would be to investigate more detailed aspects and strengths of these benefits for health and well-being, using also other types of indicators and datasets, in the case of the Stockholm metropolitan area.

Even though we found significant variations in shares of nature-based green–blue areas with socio-economic conditions, the present results also show that most of the population in the Stockholm region has at least a minimum amount of such green–blue areas in their surroundings. No particular population category is totally deprived (and only surrounded by dense grey areas), with parks, for example, available in comparable amounts across the whole income range. However, this analysis presented is location-based and does not weight local results by the amount of people at each local data point when calculating available area shares in the local environment. Local population density strongly increases with lower income (Figure 3), and with increasing population diversity (Figure 8). Thus, per capita shares (i.e., absolute amount per person) will show increasing differences between the more and less privileged parts of the population, compared with the main present results (associated statistics of absolute land-cover area per capita are available in Table SB).

5 | CONCLUSION

Average income level and degree of nationality homogeneity exhibit a clear positive relationship across different locations of the studied Stockholm Metropolitan region. Clear relationships are also found between income level and share of natural/nature based green–blue areas (positive trend) and man-made grey areas (negative trend) within the catchments of different populations parts in the region. In particular, the richer and nationality-wise more homogeneous (Swedish and EEA citizen) parts of the population, with greater possibilities to choose where to live, prefer to do so in low density urban zones, with <30% sealed soil surface parts, greater shares of natural or nature-based green and blue areas, and lower shares of grey industrial and commercial areas.

The considerably lower access to such areas for ethnically more heterogeneous (more non-EEA citizens) parts of the studied regional population also highlight a new dimension of ethnic segregation. Overall, the present results point at the importance of maintaining and restoring nearby natural and nature-based green–blue areas within and between urban built environments for increased well-being of urban populations. The results also call for further testing and comparative investigations of the local scale associations found here between socio-economic descriptors and physical environment, by consistent application of the developed quantification approach to other parts of the world.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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