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Research Note

Inverse associations between neighborhood socioeconomic factors and green structure in urban and suburban municipalities of Stockholm County

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ABSTRACT

Stockholm is one of the greenest capitals in Europe, however, there is a concern that future densification may lead to a decrease in the physical space available for green structure (includes all kinds of vegetation). International evidence suggests that the health benefits of green structure may be strongest among the lowest socioeconomic groups whereas those same groups often experience exposure to less or lower quality green structure. The aim of the present study was to investigate whether the low-income areas in Stockholm County experience less greenness; and if the trends in greenness development over years differ between areas. We found that average neighborhood values of Normalized Difference Vegetation Index (NDVI) – an estimate of amount of vegetation – increased significantly in all area types (“urban”, “sub-urban”, “rural”) between 1990 and 2015; however, the direction of the associations between neighborhood annual income and NDVI differed between area types.

Stockholm County in Sweden has a population of approximately 2.1 million. It is divided into 26 municipalities, three of which are categorized as “urban”, eighteen as “suburban” and five as “rural” (CAMM/SLL, 2017) (Fig. S1). Stockholm is one of the fastest growing cities in Europe and has about 1 million residents (Stockholm.se). Stockholm is also one of the greenest capitals in Europe – it is surrounded by 219 nature reserves, has approximately 30% of its area covered with vegetation and about 12,000 trees planted in its streets (Stockholm.se). However, there is a concern that future densification (Haaland & van den Bosch, 2015), which is a current priority for the county, may lead to a decrease in the physical space available for green structure.

In the last decade, urban planners have become more engaged in studying the positive effects of greening the built environment, which include improving air quality, mitigating urban heat islands and improving storm-water management (e.g. Kazmierczak & Carter, 2010; Salmond et al., 2016). These ecosystem services are, however, not the only benefits from urban green structure. Growing international evidence shows that people living in urban areas with abundant greenness are healthier than people living in areas with less greenness in many aspects (Fong, Hart, & James, 2018; WHO, 2016). A multitude of international studies, including a report from WHO (WHO, 2016), suggest that increased exposure to greenness is, for example, associated with reduced mortality from cardiovascular and respiratory diseases, lower blood pressure, lower self-reported stress levels and lower levels of type-2 diabetes (Kondo, Fluehr, McKeon, & Branas, 2018). Also, increased life expectancy, better self-reported health, decreased noise annoyance, decreased risk of poor birth outcomes, and less depressive symptoms have been associated with more green structure (Fong et al., 2018; WHO, 2016).

International evidence suggests that the health benefits of urban green structure may be strongest among the lowest socioeconomic groups (for example, Dadvand et al., 2012; WHO, 2016). This is of concern because those same groups often experience exposure to less or lower quality green structure (Astell-Burt, Feng, Mavoa, Badland, & Giles-Corti, 2014; Haaland & van den Bosch, 2015; Rigolon, 2016; WHO, 2016). The aim of the present study was to investigate whether the low-income areas in Stockholm County experience less greenness, as has been reported from other cities in the world (see WHO, 2016 part 2.6.4 for review); and if the trends in greenness development over years differ between areas.

Normalized Difference Vegetation Index (NDVI) (Sellers, 1985) is today the most frequently used estimation of the quantity of greenness

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Table 1
Categories of SAMS based on the interquartile range of the area size and the type of municipality and the neighborhood (SAMS) average annual income (in Swedish crowns, SEK) of the SAMS. *** corresponds signification levels of $p < 0.001$ and CI indicates the values of the confidence interval.

	Small SAMS			Medium-small SAMS			Medium-large SAMS			Large SAMS		
Municipality	Urban	Suburban	Rural	Urban	Suburban	Rural	Urban	Suburban	Rural	Urban	Suburban	Rural
Number of SAMS	60	124	29	63	129	22	58	127	35	9	126	83
Min-max area km^2	0.05–0.53	0.04–0.54	0.14–0.54	0.55–1.29	0.55–1.29	0.56–1.26	1.32–3.37	1.32–3.49	1.32–3.46	3.78–11.65	3.6–540.36	3.54–879.36
Income SEK (± sd)	296 403 (± 78102)	267 797 (± 73395)	230 732 (± 45827)	324 257 (± 86981)	319 331 (± 107980)	235 794 (± 77785)	279 703 (± 87121)	342 243 (± 96296)	259 913 (± 52935)	257 894 (± 89410)	304 598 (± 77813)	256 133 (± 34267)
Slope (NDVI; year)	0.002*** (CI 0.0012–0.0029)	0.0024*** (CI 0.002–0.0027)	0.0021*** (CI 0.001–0.0031)	0.0021*** (CI 0.0011–0.0031)	0.0021*** (CI 0.0018–0.0025)	0.0018*** (CI 0.001–0.0027)	0.0026*** (CI 0.0018–0.0033)	0.0021*** (CI 0.0019–0.0025)	0.002*** (CI 0.001–0.003)	0.0023*** (CI 0.0013–0.0033)	0.0029*** (CI 0.0027–0.0031)	0.0028*** (CI 0.0024–0.0032)
R^2	0.042	0.169	0.0694	0.068	0.213	0.1883	0.115	0.156	0.227	0.561	0.426	0.201

in epidemiological studies (WHO, 2016) and was used to estimate area greenness in the present study. NDVI is a remotely sensed measurement obtained by visible red (RED) and near infrared (NIR) radiation interacting with photosynthetic tissue in plants, and is calculated using formula: NDVI = (NIR − RED)/(NIR + RED). NDVI values range from −1 to +1, with higher values indicating more green vegetation foliage. NDVI data for Stockholm County was estimated from Landsat 5 TM and Landsat 8 images from 1990 to 2015 at a resolution of 30 m^2 by Geografiska informationsbyrån, Stockholm, Sweden. The images were processed to calculate maximum NDVI composites for the growing season of each year, defined as May 1 to September 30.

In 1994, a nationwide classification of neighborhoods called SAMS (Small Areas for Market Statistics) was established in Sweden (SCB, 2011). The SAMS are small geographical units that are considered homogenous with regard to socio-economic characteristics, each with an average population of 1000–2000 subjects. Stockholm County is divided into 890 SAMS. In the present study, we estimated the average NDVI values for each SAMS neighborhood for the period of 1990–2015 by using the ArcGIS software (ESRI, CA, USA). However, since the SAMS neighborhoods are formed based on the number of people, rather than on the size of the area, the average NDVI values of SAMS are not easily comparable, as a larger SAMS (which would have lower population density) in Swedish conditions automatically entails a higher average NDVI value. Therefore, initially, when investigating the trends in changes of NDVI over time, the SAMS were divided into four different categories according to interquartile range of the area size (Table 1).

Linear regression analysis (Stata 13.1; StataCorp LP, USA) of average neighborhood NDVI over time showed a small but significant increase in NDVI in all area types (Fig. 1, Table 1). As expected, the average NDVI values were generally higher for SAMS in the municipalities that were classified as "suburban" and "rural" than in the ones classified as "urban". The average NDVI values were also higher in larger SAMS than in smaller ones (Fig. 1). Similar trends of increasing NDVI values from the second half of the 1900s and beyond are well-documented in northern Europe and are often explained by increased atmospheric carbon dioxide levels and ongoing global warming (Julien, Sobrino, & Verhoef, 2006; Kawabata, Ichii, & Yamaguchi, 2001; Myneni, Keeling, Tucker, Asrar, & Nemani, 1997). It is, however, possible that increasing size and age of the street trees contributes to the increasing values of NDVI over time in urban and suburban conditions.

Average annual income data for SAMS were received from Statistics Sweden (http://www.scb.se/en/) and used as the indicator of neighborhood socioeconomic status. The associations between neighborhood annual incomes and NDVI for year 2009 were analyzed by using linear regression, with NDVI as the dependent variable, and SAMS' annual income as the predictor (see Table 1 and Fig. S2 for the average income data in different area types). Since the associations between socioeconomic factors and NDVI values showed identical trends within each type ("urban", "suburban", "rural") of the area, regardless of their size, we did not differentiate between the sizes of the SAMS in this analysis. Based on a linear regression model, we modeled the relationship between annual income and the area type by using a restricted cubic spline with three nodes placed according to Harell's method. For the suburban and rural areas the curvilinear term was highly significant ($p < 0.001$), whereas in urban conditions the association was significantly linear (see Fig. 2.). Associations between SAMS' annual income and NDVI showed opposite trends depending on the type of municipality. In urban municipalities the association between income and NDVI was negative (higher income was associated with less greenness), whereas in suburban municipalities the association was positive (higher income was associated with more greenness) (Fig. 2).