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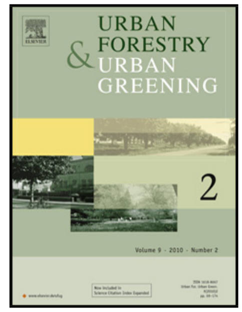

The impact of urban tree cover on perceived safety

Kostas Mouratidis

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The impact of urban tree cover on perceived safety

Kostas Mouratidis

Department of Urban and Regional Planning, Norwegian University of Life Sciences, Ås, Norway

Postal address: PO Box 5003, 1432 Ås, Norway

Phone: +47 46585309

Email: konstantinos.mouratidis@nmbu.no

Highlights

- Higher urban tree cover is associated with increased feelings of safety.
- High coverage and dispersion of trees are needed for increased perceived safety.
- Perceived safety is a possible mediator between urban nature and well-being.
- Neighborhood disadvantage has a negative impact on perceived neighborhood safety.
- Neighborhood density by itself does not lead to lower perceived safety.

Abstract

This paper investigates the impact of urban tree canopy cover on perceived safety. The paper extends previous research by examining this relationship in diverse neighborhoods within a whole city region and by accounting for neighborhood deprivation, urban form, and individual sociodemographic attributes. Based on GIS data, survey data, and municipal data, the study examines the link between tree cover and perceived safety in 45 neighborhoods of Oslo metropolitan area. Results indicate that higher urban tree cover is significantly associated with higher perceived safety, even after controlling for neighborhood deprivation, urban form attributes, and sociodemographic variables. Neighborhoods with higher tree cover are perceived as safer than those with lower tree cover. This study also finds that, when accounting for neighborhood deprivation, high-density neighborhoods are viewed as similarly safe as low-density neighborhoods. The study's findings suggest that increasing tree cover in urban areas may result in increased sense of safety and in turn in health and well-being benefits. Such an intervention could prove especially helpful in increasing the feelings of safety in denser and in poorer neighborhoods. Attention should be paid however to housing policies to ensure that physical improvements in such neighborhoods are combined with measures designed to prevent potential displacement of vulnerable social groups.

Keywords

Tree canopy cover; Sense of safety; Green space; Fear of crime; Urban vegetation; Health and well-being

1. Introduction

Urban tree cover has multiple benefits for environmental sustainability (Liu & Li, 2012; Nowak et al., 2013; Roy et al., 2012; Soares et al., 2011), resilience to environmental risks (Roy et al., 2012), as well as health and well-being (Ulmer et al., 2016). Perceived safety, which can be affected by the urban environment (Bennetts et al., 2017), also plays an important role in health and well-being (Baldock et al., 2018; Mouratidis, 2018c, 2019). Although urban vegetation has been linked with increased perceived safety (Jiang et al., 2018; Li et al., 2015; Maas et al., 2009), studies focusing on the relationship between urban tree cover and perceived safety are limited. The few studies relevant to this topic suggest a positive impact of urban tree cover on perceived safety (Kuo et al., 1998; Harvey et al., 2015).

This paper extends previous literature by examining the impact of urban tree cover on perceived safety among a number of diverse neighborhoods within a whole city region. These neighborhoods vary in terms of tree cover, urban form attributes, and sociodemographic profile. Perceived safety has been related to neighborhood socioeconomic deprivation (Sampson & Raudenbush, 2004), urban form attributes (Bramley et al., 2009), and individual sociodemographic attributes (Jansson et al., 2013). Therefore, all these factors are accounted for in the multivariate analysis of the present study. The study focuses on Oslo metropolitan area. It uses GIS data on tree cover by Hansen et al. (2013), survey data on perceived safety and individual sociodemographics (Mouratidis, 2018b), and municipal data on neighborhood living standards (Oslo Kommune, 2017).

2. Theoretical background

2.1. Urban tree cover

Urban trees provide multiple benefits revolving around environmental, economic, and societal aspects. Specifically, urban trees contribute to countering the effects of climate change by decreasing atmospheric carbon dioxide (CO2) through the processes of carbon storage and sequestration (Liu & Li, 2012; Nowak et al., 2013). Trees also increase biodiversity by providing shelter for various species (Ofori et al., 2018), improve air quality in cities (Nowak et al., 2006), improve resilience to flooding by providing storm water attenuation (Roy et al., 2012), and help reduce energy demands (Roy et al., 2012; Soares et al., 2011). These environmental benefits as well as the aesthetic, amenity, and shading benefits of urban trees generate economic benefits that usually outweigh relevant costs (Soares et al., 2011; Song et al., 2018). It should be noted however that, if not accompanied by suitable housing policies, increasing vegetation in poorer neighborhoods may lead to increased housing costs and property values, thus leading to displacement of vulnerable groups (Wolch et al., 2014). .

The societal benefits of urban trees and nature in cities in general have been widely studied (Hartig et al., 2014; Kondo et al., 2018; Markevych et al., 2017). Several scholars have been arguing for improving environmental and, at the same time, well-being outcomes through urban green space management (Carrus et al., 2015; Niemelä et al., 2010; Sandifer et al., 2015; Tzoulas et al., 2007). Urban nature can positively contribute to human well-being via a variety of mechanisms. The main mechanisms are: restoring capacities (e.g. attention restoration, stress recovery), building capacities (e.g. facilitating physical activity and social cohesion), and reducing harm (e.g. reducing exposures to air pollution, noise, and heat) (Markevych et al., 2017).

The most prominent theories on how exposure to nature affects well-being are the Attention Restoration Theory (Kaplan & Kaplan, 1989) and the Stress Reduction Theory (Ulrich et al., 1991). According to Attention Restoration Theory, natural environments help humans recover from mental fatigue generated by human information processing, because such environments do not require high levels of voluntary attention (Kaplan & Kaplan, 1989; Kaplan, 1995). Stress Reduction Theory suggests that nature has a stress-reducing and restorative influence due to its positive impact on emotional state and physiological recovery (Ulrich et al., 1991). The restorative and stress-reducing benefits of urban nature have been supported by a number of subsequent empirical studies (Nordh et al., 2009; Raanaas et al., 2012; Roe et al., 2013; Wood et al., 2018). It has been suggested that the denser the urban tree cover the stronger the stress-reducing benefits of urban nature (Jiang et al., 2016).

Urban green space may also improve health and well-being through noise reduction (Margaritis & Kang, 2017), reduction of local air pollution (Nowak et al., 2006), and mitigation of human heat stress (Lee et al., 2016). The World Health Organization (WHO) concluded that urban green space offers health benefits by improving mental health and reducing cardiovascular disease, obesity, and risk of type 2 diabetes (WHO, 2016). Evidence from panel data suggests that individuals have higher life satisfaction and less mental distress when they live in greener urban areas (White et al., 2013). Systematic reviews of literature find that urban green space is negatively associated with mortality, heart rate, and violence, and positively associated with attention, mood, physical activity, and mental health (Gascon et al., 2015; Kondo et al., 2018). Independently of green space access, evidence suggests that neighborhood tree cover provides overall health benefits (Ulmer et al., 2016).

An urban theoretical framework that focuses on the benefits of urban green space, and is therefore relevant to urban tree cover, is that of ecosystem services (Hirokowa et al., 2011; Jennings et al., 2016; Niemelä et al., 2010; Sandifer et al., 2015). Researchers suggest that local governments should understand and acknowledge the multiple ecosystem services offered by urban trees and urban forests (Hirokowa et al., 2011) and try to integrate them into communities in a socially and environmentally just way (Jennings et al., 2016). To integrate ecosystem services concepts into local policies, regulatory frameworks and planning tools may need to be reconsidered (Di Marino et al., 2019).

Despite the environmental, economic, and societal benefits of trees in cities, urban tree cover is contested by increasing urbanization and densification processes worldwide (Haaland & van den Bosch, 2015). The compact city is considered to promote aspects of environmental sustainability (Næss, 2001; Newman & Kenworthy, 1999; OECD, 2018), social sustainability (Mouratidis, 2017, 2018a; Power, 2001), and economic sustainability (Cervero, 2001), but at the same time it reduces the availability of urban green space (Bramley et al., 2009). Thus, a tension is created between the sustainability benefits of urban tree cover and those of the compact city. Compact city policies need to consider ways of integrating high urban tree cover to the greatest possible extent (Yiannakou & Salata, 2017).

2.2. Perceived safety

Perceived safety can be defined as an individual's level of comfort and perception of risk within the environment and as such is an important factor in human well-being. Perceived safety in neighborhoods, cities, and natural environments is mainly connected to fear of crime (Jansson et al., 2013; Jiang et al., 2018; Maas et al., 2009; Salesses et al., 2013). Evidence suggests that perceptions of neighborhood safety contribute to neighborhood satisfaction, emotional state, life satisfaction, and cardiometabolic health (Baldock et al., 2018; Mouratidis, 2017, 2019).

There are two main theoretical viewpoints as to how the physical environment may affect perceived safety. The first viewpoint focuses on the type and level of activity in the street and is relevant to Jane Jacobs' concept of "eyes on the street" (Jacobs, 1961) and to Cohen and Felson's Routine Activity Theory (Cohen & Felson, 1979). The second viewpoint focuses on the level of environmental disorder and is relevant to the Broken Windows Theory by Wilson and Kelling (1982).

Jacobs (1961) argued that the lack of social interaction, lack of diversity, and low pedestrian activity in urban streets might induce criminal activity by hampering surveillance between citizens. In this regard, Routine Activity Theory (Cohen & Felson, 1979) suggests that urban spaces need to foster frequent routine activities (e.g. shopping or commuting) to promote surveillance between citizens and discourage potential criminal activities. Routine Activity Theory has been extended by Jiang et al. (2018) who find positive impacts of increased routine activities on perceived safety and emphasize that a careful environmental design (including the provision of urban greenness) can increase routine activities and lead to higher perceived safety. Jiang et al. (2018) argue that people may feel safer just by visually perceiving possible routine activities in a scene (perceived routine activities theory).

The Broken Windows Theory (Wilson & Kelling, 1982) focuses on the design of the physical environment and suggests that environmental order and disorder can influence criminal activity and affect perceived safety. Empirical studies relevant to Broken Windows Theory indeed find that when people observe that certain social norms are violated (e.g. graffiti, litter), “they are more likely to violate other norms or rules” in turn causing further disorder and illegal activity (Keizer et al., 2008). However, physical environmental disorder does not only influence actual social disorder and criminal behavior. It also increases perceptions of social disorder (Hinkle & Yang, 2014), therefore contributing to lower perceived safety.

Several points made by the aforesaid theories have been incorporated into what is called Crime Prevention Through Environmental Design (CPTED), initially conceptualized by criminologist C. Ray Jeffrey. CPTED suggests environmental design strategies to increase safety that include the concepts of maintenance, activity support, natural surveillance, natural access control, and natural territorial reinforcement. Although CPTED has been criticized and evidence of its benefits remains inconclusive, CPTED strategies are nonetheless being widely deployed and a growing body of literature suggests that they can be an effective prevention tool against crime (Cozens et al., 2005) and positively affect perceived safety (Bennetts et al., 2017).

Despite evidence on the influence of environmental design and social interaction on perceived safety, it must be noted that crime is exacerbated by poverty and inequality (Fajnzylber et al., 2002; Hsieh & Pugh, 1993). In fact, a study examining perceptions of disorder finds that although physical disorder has an effect on perceived disorder, poverty and inequality pose an even greater influence (Sampson & Raudenbush, 2004). Therefore, studies that investigate the influence of the physical environment on perceptions of safety should necessarily account for measures of poverty and inequality in their analyses.

2.3. Urban tree cover and perceived safety

The impacts of vegetation on safety are widely studied (Kondo et al., 2015). Several studies find that vegetation, green space, and trees are associated with lower crime (e.g. Gilstad-Hayden et al., 2015; Kuo & Sullivan, 2001; Troy et al., 2012; Troy et al., 2016), although some quasi-experimental evidence rejects a possible causal relationship (Locke et al., 2017). Studies on perceptions of safety find that the existence and visibility of vegetation may increase perceived safety (Jiang et al., 2018; Li et al., 2015; Maas et al., 2009).

Research specifically examining the impact of urban tree cover on perceived safety is however limited. One study using photo simulations of tree density surrounding housing units finds a positive relationship between tree density and perceived safety (Kuo et al., 1998). Another study finds a positive association between street tree canopy and perceived safety (Harvey et al., 2015). The present study offers further empirical evidence and extends previous research by examining neighborhood tree cover in various neighborhoods within a whole city region. To add greater validity and robustness, the present study controls for a wide set of variables including neighborhood socioeconomic deprivation, urban form, and individual sociodemographic attributes.

3. Methods

3.1. Data sources

This study is based on survey data, GIS data, and statistical data from Oslo Municipality. The survey was conducted in May-June 2016 in the metropolitan area of Oslo for the purposes of the project "Compact city or sprawl? The role of urban form in subjective well-being" (Mouratidis, 2018b). It collected answers from a sample of 1344 individuals aged 19-94. Participants were randomly selected residents of 45 neighborhoods (Fig. 1) characterized by diversity in sociodemographic attributes, in geographical locations, and in built environment attributes. More information on the survey design can be found in Mouratidis (2018b). Table 1 presents the sample's sociodemographic profile. Tree cover was measured using GIS. Data on neighborhood socioeconomic deprivation were obtained from statistical sources of Oslo Municipality published in the year 2017 (Oslo Kommune, 2017). Detailed descriptions of the neighborhoods and their characteristics are presented in the Appendix.

Fig. 1 here

Table 1 here

3.2. Variable descriptions

Perceived neighborhood safety (perceived safety) is the outcome variable of the study, and was assessed via the survey. Respondents were asked to evaluate their neighborhood's safety, on a scale from "very low" (1) to "very high" (5).

Tree canopy cover was measured using GIS and was based on data from Hansen et al. (2013). These are global data on tree canopy. Tree canopy is defined as canopy closure for all vegetation taller than 5 m in height. This data set is representative of Oslo's tree canopy since the city is characterized by large tree species. All the main tree species in Oslo – Acer platanoides, Aesculus hippocastanum, Tilia platyphyllos, and Tilia x vulgaris (Fostad & Pedersen, 1997; Solfjeld & Hansen, 2004) – grow considerably taller than 5 m. The difference in year of measurement between the GIS data (tree canopy) and the survey (perceived safety) is not expected to affect the results as tree cover in the study's neighborhoods has remained relatively stable throughout. There are certain neighborhoods in Oslo that have been lately redeveloped and densified (e.g. Løren, Nydalen, Ensjø, Bjørvika) and in some cases lost some tree cover, but these neighborhoods are not included in the study. Based on the aforesaid GIS data set, mean percentage of tree canopy cover was measured within 250 m, 500 m, and 1000 m buffer zones from the center of each neighborhood. These are commonly used buffer zones across socio-spatial research studies on urban vegetation and green space (e.g. Dadvand et al., 2014; Ulmer et al., 2016; Wolch et al., 2011).

Urban form attributes were measured as follows. Distance to city center was measured from the centroid of each neighborhood in kilometers, along the pedestrian network. Population density was measured by dividing the population of each neighborhood by the area coverage in hectares.

Neighborhood living standards were assessed using a neighborhood deprivation index which measures the deprivation levels of a neighborhood. The index was constructed based on data from Oslo Municipality (Oslo Kommune, 2017) and therefore analysis using this index concerns only the 34 neighborhoods of the study which belong to Oslo Municipality. The neighborhood deprivation index for each neighborhood was constructed by combining three measures of overall neighborhood deprivation with the following weights: household poverty (38.46%), unemployment (38.46%), and low education (23.08%). Index weights were adjusted according to the weights of the Index of Multiple Deprivation (IMD), a widely used deprivation index with high predictive power in urban areas (Niggebrugge et al., 2005). Deprivation scores were standardized based on the average (= 100) for the whole Oslo Municipality. The deprivation scores of these 34 neighborhoods range from 42 to 190 with higher scores indicating higher deprivation.

Individual sociodemographic attributes were collected via the survey. These attributes are used as control variables in the study. Sociodemographic attributes used in the analyses of the study are: age, gender, employment status, immigrant status, living with partner or spouse, household income, presence of children in the household, and education level.

4. Results

Table 2 presents descriptive statistics of all the variables used in the study. Pearson's correlations between the study's variables and perceived safety are also presented. Tree canopy cover is significantly correlated with perceived safety. Measurements of tree canopy that are closer to neighborhood center are more highly correlated with perceived safety: tree canopy cover within 250 m buffer has the highest correlation with perceived safety ($r = 0.278$), while tree canopy cover within 1000 m buffer has the lowest correlation ($r = 0.252$). Tree canopy measurements within 250 m and 500 m buffers have similar correlations with perceived safety ($r = 0.278$ and $r = 0.271$ respectively). Distance to city center is positively correlated with perceived safety, while neighborhood density is negatively correlated with perceived safety. Neighborhood deprivation index has a strong negative correlation with perceived safety. Age, living with partner or spouse, and income each have small, but statistically significant, positive correlations with perceived safety. The other sociodemographic variables are not significantly correlated with perceived safety.

Table 2 here

Table 3 presents statistical modelling examining the impact of tree canopy cover on perceived safety. Multiple regression was used to investigate the influence of various potential independent variables and check for robustness. The coefficients presented in Table 3 are standardized coefficients.

Model A examines the statistical effect of tree cover 250 m on perceived safety accounting only for urban form variables: neighborhood's distance to city center and density. Tree cover 250 m has a significant positive effect on perceived safety. Neighborhood density is negatively associated with perceived safety, while distance to city center has no significant association with perceived safety.

Model B additionally includes neighborhood deprivation index. Since neighborhood deprivation index is measured at a municipal level, models including the index (Models B-E) are based on sample from the study's 34 neighborhoods located within Oslo Municipality. Tree cover 250 m again has a significant positive effect on perceived safety. Neighborhood deprivation index poses a strong negative effect on perceived safety. R-squared is substantially increased in Model B, showing that neighborhood deprivation index is a very important predictor that should be considered in studies examining perceived safety. Urban form variables are not significantly associated with perceived safety when neighborhood deprivation index is accounted for in Model B.

Model C examines the statistical effect of tree cover 250 m on perceived safety accounting for all potential control variables: urban form attributes, neighborhood deprivation, and sociodemographic attributes. Compared to Model B, sociodemographic variables are additionally included. R-squared increased indicating a better fit for the model. The statistical effect of tree cover 250 m on perceived safety is positive and significant ($p < 0.001$). Neighborhood deprivation index again has a significant negative association with perceived safety. Urban form variables are not associated with perceived safety. Additional physical built environment variables have also been included and assessed in this model (presence of local amenities), but are not presented since they are not significantly associated with perceived safety and they do not materially affect the coefficient of tree cover. This test however adds extra robustness to the analysis. Two sociodemographic attributes are significantly associated with perceived safety: presence of children in household and education level. These results suggest that respondents who have children in their household feel less safe in their neighborhoods and that highly educated respondents feel safer in their neighborhoods.

Models D and E are full models similar to Model C, but include tree cover 500 m and tree cover 1000 m respectively instead of tree cover 250 m. These models add extra robustness to Model C, while they also aim to assess the effect of tree canopy on perceived safety on different scales. Tree cover 500 m has a significant positive effect on perceived safety, while tree cover 1000 m has a positive but weaker effect (marginally significant, $p = 0.056$).

Table 3 here

5. Discussion

5.1. Discussion of the results

This study's outcomes indicate a significant positive statistical effect of urban tree cover on perceived safety. The effect is robust as it persists even after controlling for urban form attributes, neighborhood socioeconomic deprivation, and individual sociodemographic variables. Independently of these factors, neighborhoods with higher tree cover are perceived as safer than neighborhoods with lower tree cover.

The positive effect of tree cover on perceived safety is in line with the studies by Kuo et al. (1998) and Harvey et al. (2015) who find similar effects using different methods and spatial scales. The outcomes of the present study also support previous research indicating that the existence and visibility of vegetation may increase perceived safety (Jiang et al., 2018; Li et al., 2015; Maas et al., 2009). As Hartig et al. (2014) suggest, perceived safety can be viewed as a moderator of the well-being benefits of nature (e.g. physical activity, stress reduction), since the degree of safety felt in a natural environment can affect the extent, if any, to which such well-being benefits are being enjoyed. On the other hand, this study's outcomes, along with previous studies finding a positive association between urban vegetation and perceived safety, may suggest that perceived safety could be alternatively viewed as an additional mediator between urban nature and well-being. Since urban vegetation can induce higher perceived safety, and higher perceived safety can in turn induce higher well-being, increased perceived safety could then be considered as part of the pathways linking urban nature to well-being (for pathways see Hartig et al., 2014; Markevych et al., 2017). From an ecosystem services approach, the study's outcomes support the view that trees can be an important ecosystem service provider in urban areas. In addition to ecosystem services such as capturing air and water pollutants, providing shade and habitat, and decreasing CO_2 emissions (Hirokawa et al., 2011; Niemelä et al., 2010; Nowak et al., 2006; Ofori et al., 2018; Soares et al., 2011), urban trees may provide another ecosystem service: improving perceptions of neighborhood safety.

Why might higher neighborhood tree cover induce higher perceived safety? There are several possible explanations for this, while a combination of these explanations is also possible. (1) The first possible explanation is relevant to the Broken Windows Theory (Wilson & Kelling, 1982). It has been suggested that trees and urban vegetation in general provide signals of space boundaries and a sense of order, while empty spaces could provide signals of disorder (Kuo et al., 1998; Troy et al., 2016) and encourage illegal activity (Keizer et al., 2008). Such sense of social order provided by trees and other types of vegetation may induce higher perceived safety (Hinkle & Yang, 2014). It should be noted that vegetation needs to be well-designed and maintained to have such an impact (Jansson et al., 2013). (2) The second possible explanation is relevant to Jane Jacobs' concept of "eyes on the street" (Jacobs, 1961), Routine Activity Theory (Cohen & Felson, 1979), and Perceived Routine Activities (Jiang et al., 2018). Trees may promote use of urban spaces and induce higher social activity resulting in greater surveillance among citizens, discouragement of potential criminal activities, and in turn in increased feelings of safety (Branas et al., 2011; Jiang et al., 2018; Kuo & Sullivan, 2001). In addition, the visual perception of routine activities taking place in an urban space may also directly increase perceptions of safety (Jiang et al., 2018). (3) The third possible explanation is relevant to the positive impact of nature on emotional state. Urban trees may improve emotional state, reduce stress, and reduce exposure to stressors such as noise and heat (Hartig et al., 2014; Kondo et al., 2018; Markevych et al., 2017; Ulrich et al., 1991; White et al., 2013). Denser urban tree cover results in stronger stress-reducing benefits (Jiang et al., 2016). Trees may also contribute to a more scenic and aesthetically pleasant built environment, which increases feelings of happiness (Seresinhe et al., 2019). Happier and more relaxed residents may in turn feel safer in their neighborhood, as feelings of happiness, anxiety, and safety are interrelated (Mouratidis, 2019).

Another finding that arises from the present study is that neighborhood socioeconomic deprivation has a strong impact on perceived safety. As results in the study suggest, neighborhood deprivation, influenced by socio-spatial inequality, has a much stronger impact on perceived safety than the physical environment. This has also been supported by Sampson and Raudenbush (2004). However, in line with their findings and in line with CPTED (Bennetts et al., 2017), the physical environment – and in this case urban tree cover – can still considerably affect perceived safety.

Moreover, this study's outcomes suggest that although higher-density neighborhoods are viewed, on average, as less safe than low-density neighborhoods, this is mainly due to higher neighborhood socioeconomic deprivation often present in such neighborhoods and not because of the urban form density itself. This is indicated in the study's analysis that shows that density has no significant association with perceived safety when accounting for neighborhood deprivation. This finding possibly explains the main reason why previous studies have found perceived safety to be lower in denser neighborhoods (Bramley et al., 2009; Mouratidis, 2017, 2019).

A final important finding of the study is the positive association between education level and perceived safety. Residents with college or university education seem to feel, on average, safer in their neighborhoods compared to residents without tertiary education. The statistical effect is small but statistically significant. This association may indicate that highly educated citizens are better informed on safety issues and therefore feel slightly safer. In addition to providing education opportunities for all citizens, local governments and civil society organizations should aim to inform citizens about neighborhood safety issues, striving to reach out to vulnerable social groups which may have less access to such information.

5.2. Policy implications

Increasing tree cover can be a strategy towards improving the sense of safety in cities. This could prove particularly useful in denser and poorer neighborhoods. Such neighborhoods are usually perceived as less safe, as results from the present study and previous studies (Bramley et al., 2009; Mouratidis, 2017) suggest, and may also be less green (Bramley et al., 2009; Nesbitt et al., 2019). Increasing tree cover density can be done in a variety of ways such as by increasing street trees, placing more trees in backyards, courtyards, and private gardens, increasing public green space, and placing more trees in existing public green space. Trees should be well maintained to offer perceived safety benefits (Jansson et al., 2013).

As results from this paper suggest, the impact of tree cover on perceived safety weakens the further away the tree cover density is located. The analysis of different buffer zones of tree cover density indicates that the higher the proximity to trees the higher the perceived safety benefit. Therefore, to offer the highest perceived safety benefits, trees should be placed in all the areas covered by the neighborhood, rather than being concentrated only in one part of the neighborhood, in order to offer equal proximity to all residents. Ideally, trees, in form of street trees or trees in parks, gardens, and courtyards, should be visible from each dwelling. This would offer direct restorative, stress-reducing, and potentially perceived-safety benefits to the resident. To achieve a high coverage and dispersion of trees within the neighborhood, a diversity of green space and tree planting solutions is necessary.

A final yet important policy consideration is that although increasing tree cover could offer much-needed perceived safety benefits in deprived neighborhoods, such physical improvements may result in increased land values and housing costs, thus causing displacement of vulnerable social groups (Wolch et al., 2014). To prevent this, green infrastructure projects should be accompanied by socio-spatial justice provisions and suitable housing policies.

5.3. Future research

This study has a few limitations. First, the dependent variable of perceived safety was measured by one single-item question. In the future, using a set of more sophisticated measurements of perceived safety might enhance the validity of the findings. Second, future studies could ask participants about perceptions of police coverage in the neighborhood and the existence of citizens' initiatives such as neighborhood watch in order to examine whether controlling for such variables would affect the results. Third, it is possible that there is, to some extent at least, a two-way relationship between tree cover and perceived safety. Trees may induce feelings of safety, but higher perceived safety may itself lead to higher residents' willingness to plant and maintain more trees in private or semi-private green space. Future studies could explore this topic further using longitudinal and experimental research designs that shed more light on the existence and the direction of causality. Fourth, this study is based on a specific geographical, social, and cultural context. Oslo is a relatively prosperous, safe, and green city compared to most cities worldwide. It should also be mentioned that Norwegian citizens tend to have a strong connection with nature, and this may affect how they perceive urban tree cover or how they are affected by it. It would be useful to replicate this type of study in different settings to allow examination of the impact of geographical, social, and cultural differences on the relationship between urban tree cover and perceived safety.

6. Conclusion

This paper contributes to knowledge on the societal benefits of urban nature by providing new insights into the relationship between urban tree cover and perceived safety. The paper has examined the possible impact of neighborhood tree cover on perceptions of neighborhood safety among a number of diverse neighborhoods. Higher tree cover is found to be associated with higher perceived neighborhood safety. The effect is significant both statistically and practically (effect size), and persists even after statistically controlling for urban form attributes, neighborhood socioeconomic deprivation, and individual sociodemographic variables. Neighborhood deprivation is found to be strongly associated with lower perceived neighborhood safety. Neighborhood density, on the other hand, has no association with perceived neighborhood safety when accounting for neighborhood deprivation.

According to the results of the present study, increasing tree cover can be a strategy towards improving the sense of safety in cities. This could prove particularly useful in poorer neighborhoods, which are characterized by lower perceived safety. The study's findings suggest that high coverage and dispersion of trees within the neighborhood are needed for perceived safety benefits. This can be done in a variety of ways such as by increasing street trees, placing more trees in backyards, courtyards, and private gardens, increasing public green space, and placing more trees in existing public green space. Housing policies should, at the same time, ensure that such physical improvements in neighborhoods are combined with measures designed to prevent potential displacement of vulnerable social groups.

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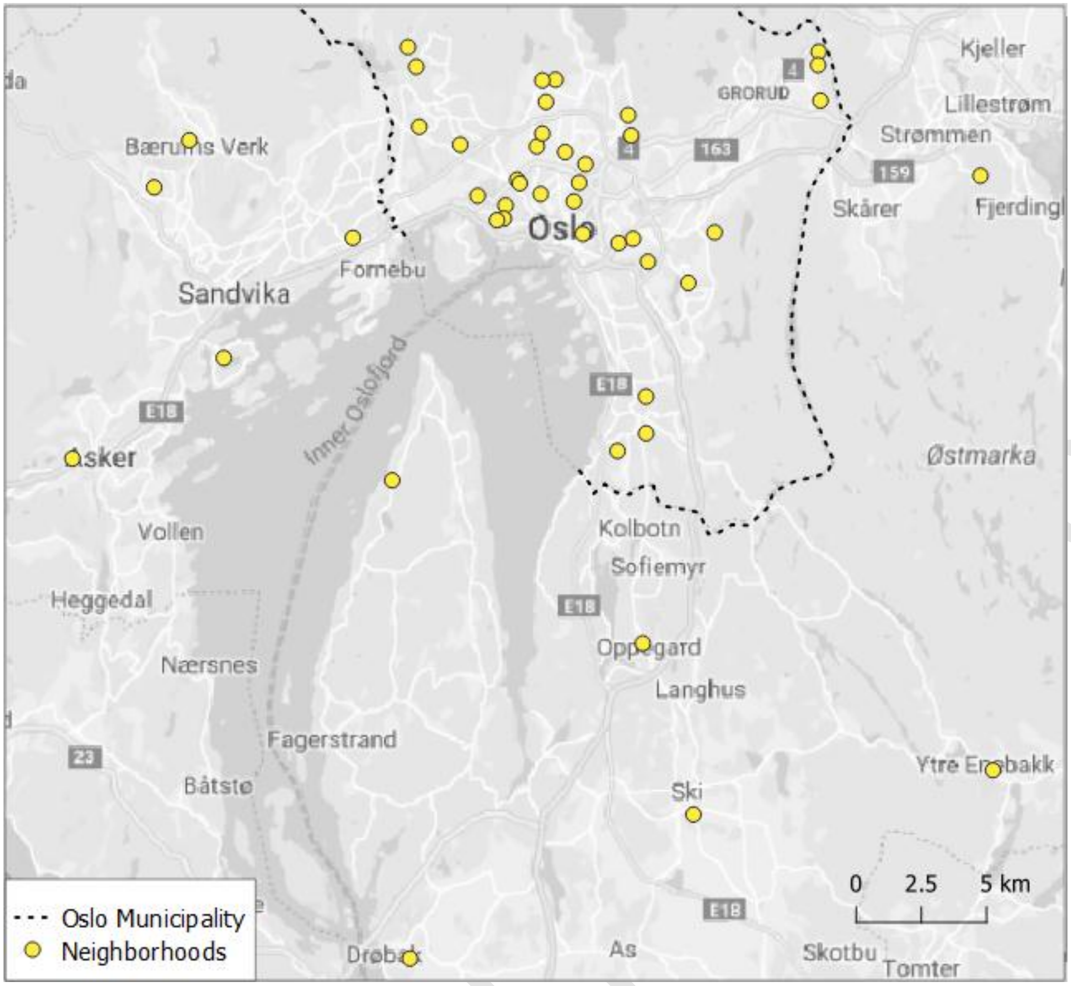

Fig. 1. Case neighborhoods within Oslo metropolitan area.

Table 1. Sociodemographic characteristics of the survey respondents.

Sociodemographic variables	Survey respondents (N=1344)	Population
	Mean	Mean
Age (for aged 18 or older)[1]	50.16	46.30
Unemployed[2]	2.50%	3.50%
Living with partner/spouse[1]	61%	48%
Non-Norwegian[1]	9%	21%
Adjusted household income (1000s NOK)[1]	642.2	582.98
Household size (persons)[1]	2.22	1.94
Number of children in household[1]	0.54	0.46
Household with children[1]	32%	26%
Respondent is female[1]	53.40%	50.30%
Respondent has college degree or higher[2]	79%	47%

Notes: [1]Population mean refers to the counties of Oslo and Akershus. [2]Population mean refers to Oslo Municipality.

Sources: Statistics Norway (2017) and European Commission (2016).

Table 2. Descriptive statistics.

Variables	N	Min/Max	Mean	s.d.	Correlation with perceived safety
Perceived neighborhood safety					
Perceived safety	1330	1/5	4.22	(0.82)	
Tree canopy cover					
Tree cover 250 m (%)	45	2.32/55.56	24.15	(13.21)	0.278*
Tree cover 500 m (%)	45	5.07/64.66	26.98	(14.67)	0.271*
Tree cover 1000 m (%)	45	9.60/72.96	30.54	(15.02)	0.252*
Urban form variables					
Distance to city center (km)	45	1/46.20	10.50	(10.00)	0.191*
Population density (persons/ha)	45	14/306	87.00	(77.31)	-0.266*
Neighborhood living standards					
Neighborhood deprivation index[1]	34	42/190	91.40	(41.18)	-0.419*
Sociodemographic variables					
Age	1344	19/94	50.16	(15.71)	0.103*
Female	1331	0/1	0.53	(0.50)	0.016
Unemployed	1339	0/1	0.03	(0.16)	-0.042
Non-Norwegian	1342	0/1	0.09	(0.28)	-0.030
Living with partner/spouse	1329	0/1	0.61	(0.49)	0.089*
Adjusted household income (1000s NOK)[2]	1259	35/4330	642.2	(321.08)	0.111*
Household with children	1334	0/1	0.32	(0.47)	0.047
College degree or higher	1341	0/1	0.79	(0.41)	0.055

Notes: *$p<0.01$. Perceived neighborhood safety and sociodemographic variables are measured at an individual level, while tree canopy cover, urban form variables, and neighborhood living standards are measured at a neighborhood level. [1]Measured for each of the study's 34 neighborhoods located within Oslo Municipality. [2]Annual household income divided by the square root of household size.

Table 3. Regression models examining the impact of tree cover on perceived safety.

Variables	Perceived safety				
	A	B	C	D	E
Tree canopy cover					
Tree cover 250 m	0.190***	0.153**	0.174***		
Tree cover 500 m				0.171**	
Tree cover 1000 m					0.138[a]
Urban form variables					
Distance to city center	-0.026	0.007	-0.020	-0.065	-0.062
Density	-0.146***	0.032	0.010	-0.027	-0.040
Neighborhood living standards					
Neighborhood deprivation index		-0.362***	-0.361***	-0.370***	-0.385***
Sociodemographic variables					
Age			-0.021	-0.022	-0.025
Female			0.002	0.002	0.004
Unemployed			-0.009	-0.010	-0.007
Non-Norwegian			0.029	0.030	0.028
Living with partner/spouse			0.043	0.045	0.044
Adjusted household income			0.041	0.040	0.039
Household with children			-0.080*	-0.080*	-0.083*
College degree or higher			0.075*	0.077*	0.077*
Summary statistics					
N	1325	940	865	865	865
R-squared	0.086	0.191	0.215	0.213	0.208

Notes: [a]$p<0.10$, *$p<0.05$, **$p<0.01$, ***$p<0.001$. All coefficients shown are standardized.

Appendix

Table A1. Case neighborhoods of western part of Oslo.

Neighborhood name	Location	Deprivation index	Population density (persons/ha)	Distance to city center (km)	Tree cover (%) 250m	Tree cover (%) 500m	Tree cover (%) 1000m	Sample size (persons)
St. Hanshaugen	Municipality	76	203	2.3	10	14	15	62
Frogner A	Municipality	89	135	2.8	13	12	18	8
Frogner B	Municipality	91	306	2.6	11	13	15	20
Frogner C	Municipality	111	94	2.8	21	17	16	17
Skøyen	Municipality	56	46	4.2	37	39	27	16
Majorstuen A	Municipality	82	221	3.1	2	5	14	57
Majorstuen B	Municipality	82	247	2.9	2	7	12	35
Holmen	Municipality	57	30	6.0	29	25	31	13
Hovseter	Municipality	82	76	7.4	25	26	27	22
Holmenkollen A	Municipality	65	24	10.5	27	33	44	19
Holmenkollen B	Municipality	65	60	10.6	52	65	59	20
Grefsen	Municipality	54	97	7.6	30	38	37	26
Lofthus	Municipality	42	50	5.6	15	18	21	17
Ullevål	Municipality	52	57	4.0	18	18	20	22
Berg	Municipality	52	35	4.6	38	23	18	20
Korsvoll	Municipality	57	31	6.5	45	48	52	11
Kringsjå	Municipality	57	73	6.8	36	41	44	12
Nordberg	Municipality	91	26	5.8	27	29	28	13
Rykkinn	Metro area		26	19.2	19	15	21	44
Bærums Verk	Metro area		42	17.7	23	27	40	38
Stabekk	Metro area		26	8.6	40	32	33	11
Asker	Metro area		23	25.0	22	31	33	41
Nesøya	Metro area		14	21.6	56	47	44	45

Table A2. Case neighborhoods of eastern part of Oslo.

Neighborhood name	Location	Deprivation index	Population density (persons/ha)	Distance to city center (km)	Tree cover (%) 250m	Tree cover (%) 500m	Tree cover (%) 1000m	Sample size (persons)
Grønland	Municipality	190	205	1.0	5	6	10	100
Sagene	Municipality	95	267	3.5	16	17	16	57
Grünerløkka lower	Municipality	111	171	1.5	16	12	13	53
Grünerløkka upper	Municipality	122	244	2.3	8	7	11	72
Vålerenga	Municipality	115	130	2.5	9	10	15	52
Etterstad	Municipality	93	72	3.2	7	8	17	14
Vestli	Municipality	188	126	13.6	27	41	49	3
Tokerud	Municipality	188	81	13.8	17	37	44	16
Stovner	Municipality	105	36	13.1	17	16	32	7
Holmlia	Municipality	104	62	10.8	27	37	42	13
Hauketo	Municipality	182	32	10.1	39	44	50	12
Torshov	Municipality	88	135	3.3	11	12	11	71
Hellerud	Municipality	57	44	7.7	35	41	48	33
Høyenhall	Municipality	77	52	4.4	19	22	23	13
Østenjø	Municipality	81	55	6.4	20	23	25	16
Nordstrand	Municipality	53	38	8.4	27	31	40	14
Ski	Metro area		22	26.4	23	25	25	42
Oppegård	Metro area		27	17.6	26	33	42	51
Drøbakk	Metro area		38	36.0	39	35	40	26
Bjørnemyr	Metro area		26	46.0	54	49	45	35
Ytre Enebakk	Metro area		22	32.6	21	31	35	32
Blystadlia	Metro area		88	20.0	27	59	73	23