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Is green space associated with reduced crime? A national-scale study from the Global South

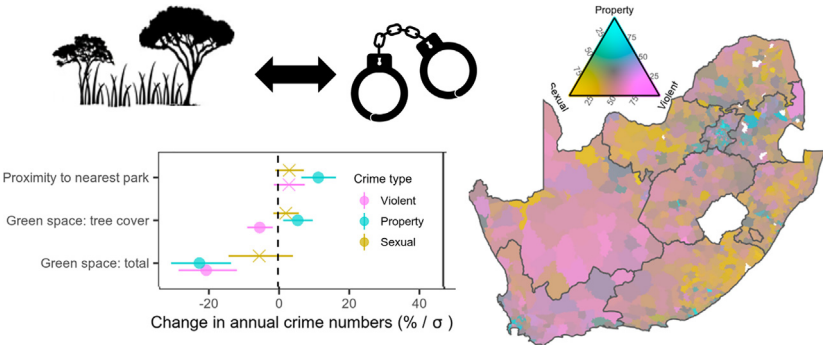
Zander S. Venter [a,*], Charlie Shackleton [b], Andrew Faull [c,d], Lizette Lancaster [c], Gregory Breetzke [e], Ian Edelstein [f]

[a] Norwegian Institute for Nature Research - NINA, Sognsveien 68, 0855 Oslo, Norway
[b] Department of Environmental Science, Rhodes University, Makhanda 6140, South Africa
[c] Institute for Security Studies, 0181, South Africa
[d] Centre of Criminology, University of Cape Town, 7700, South Africa
[e] Department of Geography, Geoinformatics and Meteorology, University of Pretoria, 0002, South Africa
[f] Safety and Violence Initiative, University of Cape Town, 7701, South Africa

HIGHLIGHTS

- Total green space associated with less violent and property, but not sexual crimes
- Characteristics of green space alter the association with crime.
- Tree cover and park accessibility associated with higher property crimes
- Novel and nuanced contribution to literature currently dominated by the Global North
- Need for further research including experimental studies to address confounding factors

GRAPHICAL ABSTRACT



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ABSTRACT

Assumptions about the link between green space and crime mitigation are informed by literature that overwhelmingly originates in the Global North. Little is known about the association between green spaces and crime in the Global South. We utilized 10 years of precinct-level crime statistics (n = 1152) over South Africa, a global crime hotspot, to test the hypothesis that green space is associated with reduced crime rates. We found that, after controlling for a number of socio-demographic confounders (unemployment, income, age, education, land use and population density), for every 1% increase in total green space there is a 1.2% (0.7 to 1.7%; 95% confidence interval) decrease in violent crime, and 1.3% (0.8 to 1.8%) decrease in property crime, with no effect on sexual crimes. However, the direction of the association changed for property crimes when exploring the effect of green space characteristics including tree cover and park accessibility. Property crimes increase by 0.4% (0.1 to 0.7%) with a percentage increase in tree cover, and by 0.9% (0.5 to 1.3%) with every kilometer increase in proximity to a public park. Further research, including experimental studies, is needed to better isolate causal mechanisms behind crime-green space associations, especially considering that green space may map to race and income inequality and that there may be more crime reporting in affluent areas. Nevertheless, our results provide a complementary contribution to the evidence from the Global North, highlighting the need for more nuanced definitions of green space and its characteristics when considering links to crime. When viewed in light of the broader suite of ecosystem services provided by green space, our results support urban greening as a major strategy towards achieving just and sustainable cities and towns.

* Corresponding author.
E-mail address: zander.venter@nina.no (Z.S. Venter).

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1. Introduction

Research examining the relationship between green space and crime is not new. A plethora of studies have examined this association with researchers often finding an inverse relationship (Branas et al., 2011; Kim, 2019; Kuo and Sullivan, 2001a, 2001b; Lovasi et al., 2013). That is, higher percentages of nature and/or levels of green space or cover at various spatial scales (ranging from buildings to cities) have been found to be associated with lower rates of crime across a range of categories. 'Green space' in this instance refers to a variety of natural environments which are green and have been operationalized in a number of ways in previous studies, including vegetation (Kuo and Sullivan, 2001a, 2001b; Wolfe and Mennis, 2012); urban parks (Gilstad-Hayden et al., 2015); tree density (Kardan et al., 2015); tree canopy cover (Troy et al., 2012); and urban trees (Donovan and Prestemon, 2012; Kondo et al., 2017), among many others. Regardless of its operationalization, the vast majority of studies have found that an abundance of green space or greenery most often correlates with lower rates of criminal activities.

The majority of research examining this association has however emanated from the Global North, particularly the United States (US), with researchers using an array of study designs, statistical methods and units of analysis. One of the first studies was undertaken by Kuo and Sullivan (2001a) who examined the relationship between vegetation and crime in an apartment complex in an inner-city neighbourhood in Chicago. They found that the greener a building's surroundings, the fewer crimes reported. At the broader neighbourhood level, Wolfe and Mennis (2012) examined the influence of vegetation on various crime types in Philadelphia after controlling for a number of socioeconomic indicators and found green spaces to be most strongly associated with a reduction in violent crime followed by various types of property crime. Studies in other US cities including Boston (Crewe, 2001), Baltimore (Troy et al., 2012), Portland (Donovan and Prestemon, 2012) and Minneapolis (Eckerson, 2013) have also found green space to be associated with reduced crime regardless of the measurement of greenspace, type of crime examined, or unit of analysis employed.

Much less research has been conducted outside the US, as evidenced in the collection of literature synthesised in two recent reviews on the topic by Bogar and Beyer (2016) and Shepley et al. (2019). A few studies, reporting similar results to the US work, have been conducted in Canada (Odunayo, 2020) and Australia (Kimpton et al., 2017). However there is a deficit of evidence for countries in the Global South (lower-income countries on one side of the global socio-economic divide), despite many being disproportionately affected by violent crime. Notable exceptions include Escobedo et al. (2018), who found strong negative associations between various treescape variables (tree height, basal area, crown area) and homicide in Bogota, Columbia; Ambrey and Shahni (2017) who found that green space was associated with enhanced wellbeing and lower crime rates in Tehran, Iran; and Sukartini et al. (2021) who reported lower crime rates, generally, and robbery, specifically, for wards with parks compared to those without or that lost parks in the three largest metropoles in Indonesia.

There are several causal pathways by which green space may reduce crime risk. From a psychological perspective, green space has been found to promote attention restoration (Markevych et al., 2017), reduce stress (Hedblom et al., 2019), encourage physical activity (Mytton et al., 2012), as well as facilitate social interaction and cohesion (Jennings and Bamkole, 2019), all of which may lower an individual's propensity for aggression and violence. The key theory in this regard is the Attention Restoration Theory (ART) which posits that natural features in the local environment restore cognitive control and attention (Berman et al., 2008; Berto, 2005). The theoretical linkage between crime and green space is, therefore, indirect and mediated by self-control restoration. The ability to assert cognitive control (i.e., self-control) is critical for not only blocking out extraneous stimuli, but also to inhibit or suppress undesirable thoughts, feelings, or behaviors (Kaplan and Kaplan, 1989; Kuo and Sullivan, 2001b). Accordingly, the presence of nature can lead to the inhibition of criminal behavior (Kaplan and Kaplan, 1989; Staats et al., 2016; Wilkowski and Robinson, 2008; Wilkowski et al., 2010) and potentially lower rates of certain types of interpersonal crimes such as assault. From a more practical perspective, certain types of green spaces (such as parks) may reduce opportunities for crime by encouraging surveillance, aligning with the influential 'eyes on the street' theory of Jane Jacobs (1961). Based on this perspective, the public may provide community guardianship in green environs and, in doing so, collectively work to prevent or reduce crime based on their tendency to intervene and/or reprimand individuals engaging in certain types of crime (such as vandalism) or contact law enforcement if they witness a crime. Conversely, it is also possible that certain green spaces may have reduced internal and external visibility offering less opportunities for surveillance by legitimate users thus providing would-be offenders with greater opportunities for criminal behavior. A limited number of studies have shown how certain types of green spaces may in fact increase the risk of crime (see Abu-Lughod, 2006; Groff and McCord, 2012; McCord and Houser, 2017) given that they attract large numbers of people and reduce the effectiveness of neighbourhood social controls (e.g. police patrols, community watch; Sampson, 2012), thus providing an increased opportunity for motivated offenders.

Despite the association between green space and crime being relatively consistent in the literature, increasing evidence suggests that the quality and characteristics of green spaces, and their surrounding areas, may mediate the green space-crime relationship. Green space quality in this instance refers to the level of greenness, the maintenance of structures and amenities (if any), as well as the inclusion of safety features (Sadler et al., 2017). High quality green spaces have been found to encourage visitation and concomitant social cohesion, thus providing a disincentive for criminal behavior (Garvin et al., 2013; Lorenc et al., 2012; Wolfe and Mennis, 2012). Conversely, low quality, unmaintained green spaces have been found to be more criminogenic and provide opportunities for would-be offenders to gather without surveillance or fear of being caught if they engage in criminal activity (Kimpton et al., 2017; McCord and Houser, 2017). In terms of the composition of the neighbourhood itself, Kim and Kim (2020) found that neighbourhood greenery had a negative relationship with crimes for low-income neighbourhoods in Austin, Texas but a positive relationship with crimes for high-income neighbourhoods, while Boessen and Hipp (2018) found neighbourhoods near green spaces (parks) have more violence (aggravated assault and robbery) than other neighbourhoods when they are located in neighbourhoods with higher levels of Latinos and those aged 16 to 29. Finally, Troy et al. (2012) found that the inverse relationship between crime and green space was 40% greater for public (industrial) than for private (residential) land in Baltimore. Understanding how these colluding factors combine to influence the behaviors of potential offenders, victims, and guardians is necessary to better understand the spatial distribution of green space crime and provide an evidence base for crime prevention initiatives.

Although much is known about the association between green space, vegetation and crime, there is a dearth of evidence from the Global South which is often where violent crime and the harmful impact thereof is greatest. As with most criminological theories, laws and axioms, it is unknown if this association is applicable in an African context, in general, and in the South African context, specifically. This is important to ascertain as it provides a measure of academic credibility and international generalizability to an association generally accepted by most environmental criminologists as becoming increasingly central to place-based interventions aimed at reducing the risk of crime in neighbourhoods. We expect that the association between crime and green space may differ in the Global South compared to the Global North because poverty and growing urbanisation, both factors that have previously been found to be associated with increased rates of crime (Breetzke and Cohn, 2012), are much higher. In addition, the higher rates of urbanisation in the Global South are often associated with lower levels of greenspace (Colding et al., 2020), which in turn may influence crime rates.

Finally, most prior research has examined the relationship between green space and crime at a citywide level. We are unaware of any research that has examined this association at a national scale. The largest studies that we are aware of include Ogletree (2019) who examined the association

between green space and crime across 301 US cities and found greater amounts of green space to be associated with less property and violent crime risk, with only three cities showing contrary associations for violent crime.

In contrast, we examine the impact of green space on crime across the whole of South Africa (1152 police precincts), a country firmly situated in the Global South. Specifically, we use a series of generalized additive regression models to examine the impact of green space – defined as vegetation surfaces and tree canopies - on violent, property and sexual crime. Based on existing international evidence, we hypothesize that green space will be associated with lower crime rates in South Africa. We also explore whether the association between crime and green space changes depending on green space characteristics (tree cover and park access are chosen in our study based on data availability). We explore the link between green space and crime using a national dataset of reported crime rates at the police precinct level, after controlling for a number of potential confounding factors. South Africa has been described as a 'country at war with itself' (Altbeker, 2007) with rates of crime, especially violent crime, consistently above international averages. In 2019, the country's murder rate was six times the global average (UNODC, 2019), while in 2020 the Gallup Law and Order Index (2020) ranked it among the least safe in the world, with residents constantly living in fear, and having little trust in local policing authorities. Only Liberia, Venezuela, Gabon, and Afghanistan ranked below South Africa in terms of perceived safety and security. Any evidence that can better elucidate the causes of crime or, more importantly, possibly inform mitigation measures, is of value. Having such high crime rates makes South Africa a compelling setting to test the relationship between green space and crime 'at the extreme'.

2. Methods

2.1. Crime data

Station-level crime statistics between 2010 and 2019 were obtained from the South African Police Service. Crime statistics were aggregated over time to generate annual averages per geographical unit and therefore our study follows a cross-sectional and not longitudinal design. We linked the police station locations to geographical units defining the police precinct boundaries. These polygons were used as the primary unit of aggregation and analysis (Fig. 1B). Crime data were aggregated into three categories commonly used in the broader green space-crime literature (Shepley et al., 2019), including violent, property and sexual crimes (see sub-categories in Fig. 1A). We calculated the average annual crime rate per 100,000 citizens for each police precinct. Population density data were obtained from the most recent (2011) South African national census provided by Statistics South Africa (http://www.statssa.gov.za/) and curated by AfricaScope (https://africascope-sa.com/).

2.2. Environmental data

All environmental variables were calculated for areas within 1 km of any residential or commercial land. We did this because a one kilometer buffer zone around residence and industry/workplace defines the space in which most of daily human activity occurs, and is a threshold commonly adopted in environmental epidemiology literature to quantify environmental exposure (Shin et al., 2020). Second, criminological theory such as the routine activity theory holds that most offenders are much more likely to

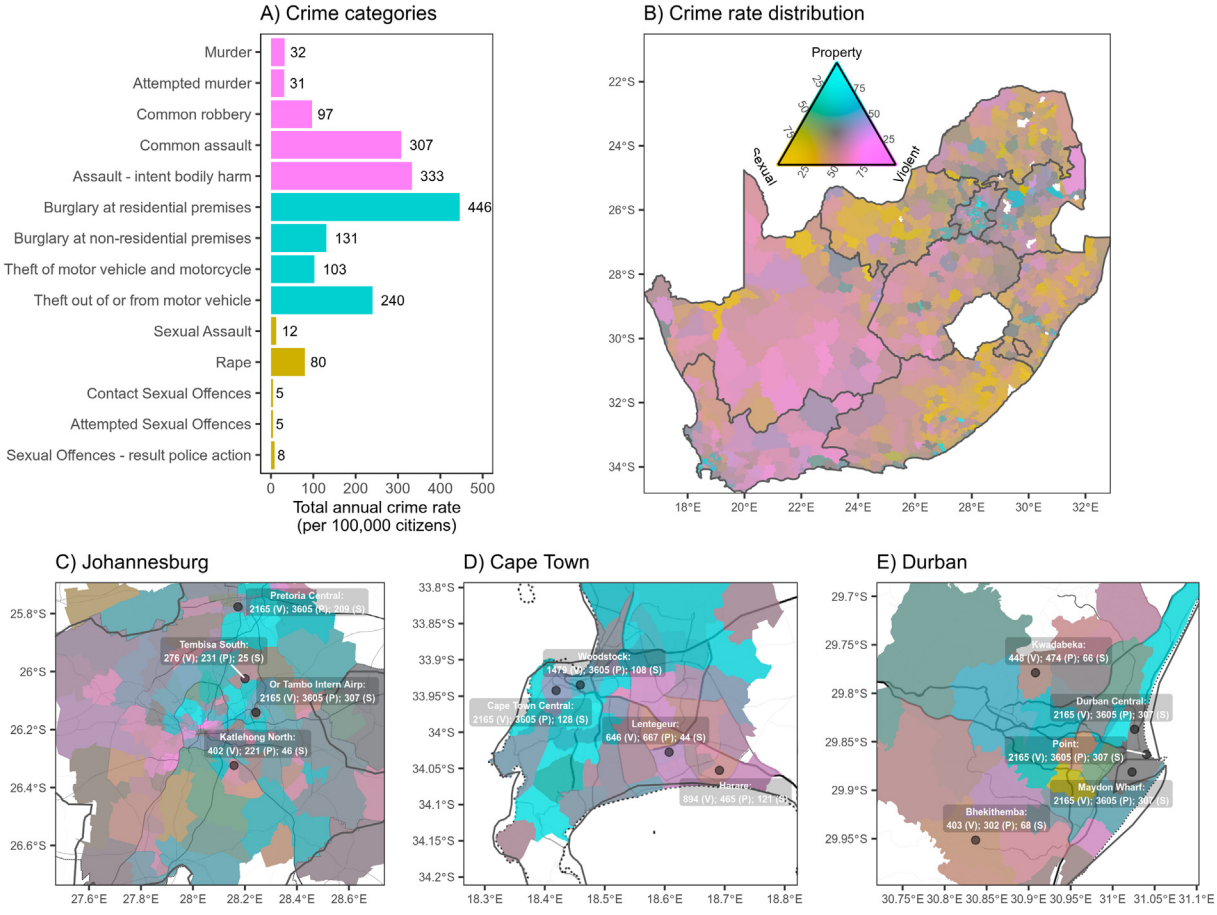

Fig. 1. National crime rates over South Africa per sub-category of crime used in the study (A). Crime rates were aggregated into violent (V), property (P) and sexual (S) crimes for police precincts (n = 1152) over South Africa (B). Crime rates within each major category are scaled between 0 and 100 and mapped in a trivariate color palette. Zoomed maps of three major cities are plotted in C, D and E. Two precincts with the highest and lowest cumulative crime numbers are labelled in the city-level maps to illustrate the range of the data. The color key for the crime categories is located in B.

intercept a suitable crime target within walking distances of their home and workplace (Felson, 2013); this has also been found to be the case in some studies in South Africa (see Gonsalves et al., 2015).

We used a remote sensing and machine learning workflow outlined in Venter et al. (2018) and Venter and Sydenham (2021) to map impervious (i.e. urban sealed-surfaces) and non-impervious (vegetation, water and bare soil) surfaces across South Africa. Total green space was defined as any vegetated surfaces, while tree cover was defined within green spaces as any woody vegetation greater than 2 m tall. The remote sensing workflow utilized Sentinel-2 imagery (10 m resolution) and orthophotos (25 cm resolution) in a supervised Random Forest classification model (Breiman, 2001) to create a national map of green space and tree cover at 2 m resolution (see Supplementary Fig. S1). Random Forest is an ensemble machine learning method that deals well with large and noisy input data and is robust against overfitting. All remote sensing data collection and processing was performed in the Google Earth Engine cloud-computing platform (Gorelick et al., 2017).

Our custom map of green space was supplemented with a 20 m resolution National Land-Cover map (Thompson, 2018) which allowed us to calculate percentage cover of informal settlements, commercial/industrial land, and agricultural land. We also calculated the average Euclidean distance to the closest public park for all residences in the given police precinct. Here parks were defined by OpenStreetMap (OSM) data (https://www.openstreetmap.org/) as geometries with attribute descriptions including 'park', 'playground' and 'protected area'.

2.3. Socio-demographic data

We used socio-demographic data from the 2011 census (http://www.statssa.gov.za/) including: population density; monthly income per capita (US$1 = approx. R7.50 in 2011); education level (percentage of residents with a matric certificate); youth percentage as a proxy of age demographic skewness (percentage of residents aged 16 to 30 years); employment (percentage of residents employed). We also calculated a measure of spatial income inequality defined as the coefficient of variation in the census tract income levels within a police precinct.

2.4. Statistical analysis

To assess the associations between green space variables and crime, while controlling for potential confounders (unemployment, income, age, education, land use and population density), we used a generalized additive regression model framework using the 'mgcv' package in R (R Core Team, 2019). Generalized additive regressions are advantageous because they account for both linear and non-linear interactions between the predictor and response variables, and are able to report the partial dependence of a response variable on a selected predictor variable while controlling for the effect of all other predictors. We specified a negative binomial distribution to account for the distribution of the crime rates and accounted for the spatial autocorrelation in the data using the latitude and longitude centroids of the police district polygons. Before fitting our model we checked for collinearity in our predictor (i.e. independent) variable set and found no signs of significantly collinear variables according to best practices outlined in (Dormann et al., 2013).

3. Results

3.1. Summary statistics

During the study period (2010 to 2019) there were a total of 4.4 million violent crimes, 5.1 million property crimes, and 0.6 million sexual crimes reported across South Africa (Fig. 1A). Police precincts display a large range in crime rates; for instance a minimum and maximum of 22 and 1017 property crimes, respectively (Table 1). The relative spatial distribution of crime categories shows that cities have higher concentrations of property crimes (relative to property crimes in rural areas), while rural areas have higher concentrations of violent and sexual crimes (relative to the same categories in cities) (Fig. 1B). Within the major cities in South Africa, poorer neighbourhoods have relatively high concentrations of violent crime which exceed that of property crimes (e.g. Katlehong, Johannesburg, Fig. 1C; Harare, Cape Town, Fig. 1D; Bekhithemba, Durban, Fig. 1E).

Table 1
Summary statistics of crime, green space and covariate variables used in the analysis.

Variable	Mean	Min	Max	Standard deviation
Property crimes (# per 100,000 citizens)	1017	22	76,413	2705
Sexual crimes (# per 100,000 citizens)	126	0	3641	149
Violent crimes (# per 100,000 citizens)	910	34	54,239	1728
Green space: total cover (%)	78.59	9.18	99.54	17.26
Green space: tree cover (%)	13.02	0.06	68.79	13.05
Distance to park (km)	12.89	0.00	102.92	12.55
Area (km^2)	1065.00	1.90	19,487.25	1784.99
Population	50,785	183	376,540	55,498
Population density (people/km^2)	1039	100	32,819	2677
Unemployment (%)	9.50	0.32	37.58	4.53
Youth (% aged 16 to 30)	28.03	5.48	49.45	5.22
Education (% with matric certificate)	0.27	0.00	1.72	0.24
Income per capita (ZAR per month)	2589.98	276.28	21,964.52	2788.65
Income inequality (coefficient of variation of income per capita)	0.83	0.21	3.18	0.30
Agricultural land (%)	12.64	0.00	83.18	16.08
Industrial/commercial land (%)	2.97	0.00	78.74	6.72
Informal settlement (%)	0.93	0.00	41.53	3.14

3.2. Green space – crime associations

After controlling for a number of potential confounders (listed in the lower panel of Fig. 2) using multivariate regression models, we found that total green space was associated with lower violent and property crimes, while there was no association for sexual crimes (Fig. 2). For every 1% increase in total green space there is a 1.2% (0.7 to 1.7%; 95% confidence interval) decrease in violent crime, and 1.3% (0.8 to 1.8%) decrease in property crime. Here we report non-standardized coefficients while in Fig. 2 standardized coefficients are indicated. Tree cover had a positive association with property crime (more crime with greater tree cover) but a negative association with violent crime (Fig. 2). For every 1% increase in tree cover, there is a 0.4% (0.1 to 0.7%) decrease in violent crime, and a 0.4% (0.1 to 0.8%) increase in property crime. Proximity to parks was only associated with property crimes (Fig. 2). There is a 0.9% (0.5 to 1.3%) increase in property crimes for every 1 km increase in proximity to parks.

3.3. Interactive effects

There was an interactive effect of tree cover and total green space on property crime (Fig. 3B) where crime rates were particularly high in precincts with low total green space but high percentage tree cover. Although sexual crimes were not associated linearly (Fig. 2) with any of the green space variables, we did find a unimodal non-linear relationship with tree cover (Fig. 3C) where sexual crime rates were highest at very low or very high tree cover, but not moderate tree cover.

Although not considered as part of our central hypothesis, we present the associations for the covariates included in our model of crime rates. The variables with the largest effect sizes included income per capita and the percentage of commercial/industrial land within a precinct (Fig. 2). Property crimes were strongly associated with higher income and education levels, while violent and sexual crimes were associated with lower education levels. Police precincts with higher levels of industrial and commercial land cover were associated with elevated crime rates for all three crime categories.

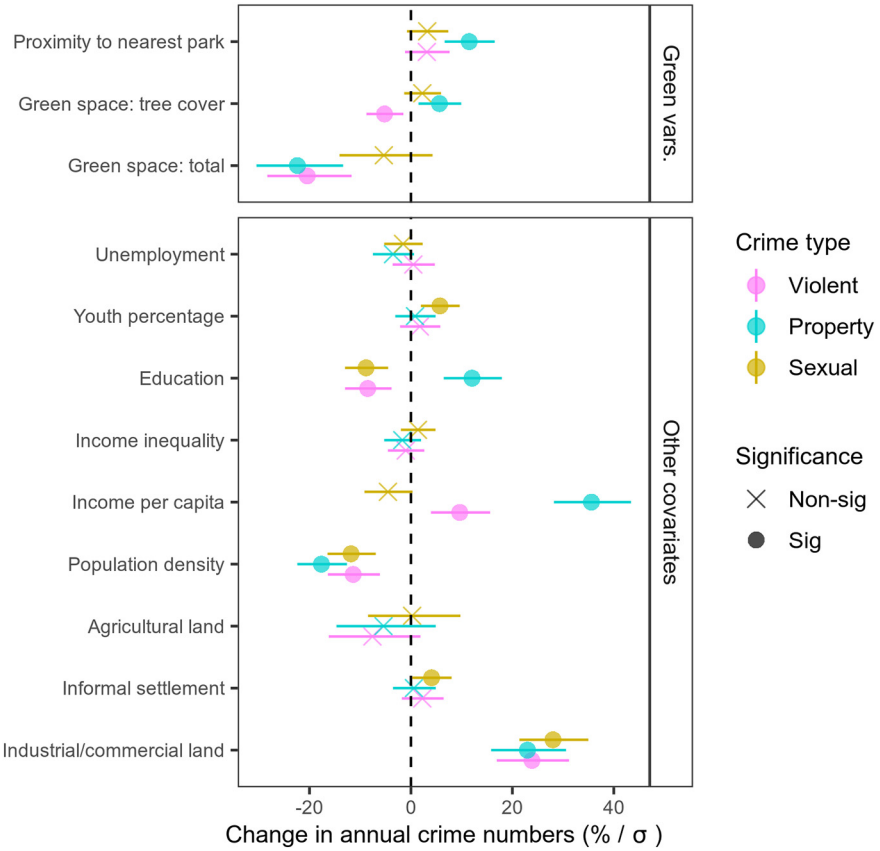

Fig. 2. Empirical estimates of the association between crime rates and green space variables (top panel), after controlling for the effects of a number of covariates (bottom panel). Estimates are standardized coefficients and expressed as percentage changes in crime rates per standard deviation (δ) increase in the explanatory variable. Each estimate is made after controlling for the effects of all other covariates in the multivariate model. Points and lines represent the model estimates and 95% confidence intervals. Non-significant estimates are marked with an "x".

4. Discussion

This study has offered the first ever national-scale analysis of the relationship between various measures of urban green infrastructure and three different classes of crime in any context. Being a national-scale analysis it avoids concerns about selection of sample sites and simultaneously increases the number of sample points which allows for robust data analysis. This study has also focused on a country in the Global South, which to date is poorly represented in the literature on this subject (Shepley et al., 2019). However, the generally high crime rates, particularly

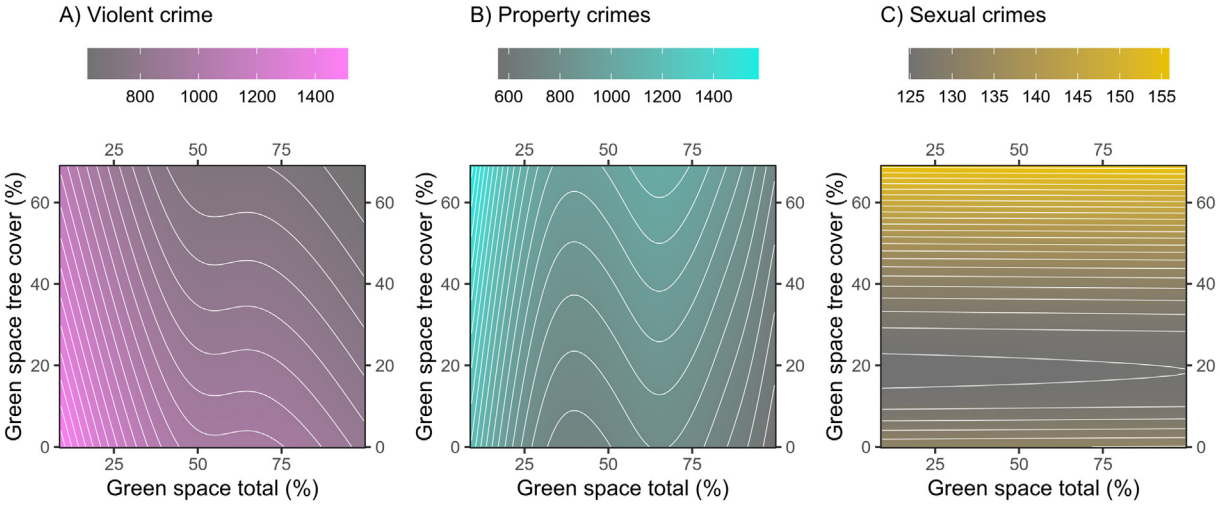

Fig. 3. Interactive non-linear effects of total green space and tree cover on crime rates for violent (A), property (B) and sexual (C) crimes. Explanatory variables are reflected by the X- and Y-axes while the magnitude in the response variable - crime rate - is reflected along the Z-axis which is depicted using a color gradient. Grey areas on the plot reflect low crime rates while colorful areas reflect high crime rates. White contour lines are plotted to show the gradient of change in the response variable. Interactive effects are generated from the statistical models which control for the effect of potential confounders.

for violent crime, in South Africa (Altbeker, 2007), and the extreme nature of its income, race and green space inequality (Venter et al., 2020) diminish its representivity of any single geographic or economic block. Nevertheless, the uniqueness of South Africa as a global crime hotspot offers a unique opportunity to examine the oft-reported negative relationship between crime rates and green space at the 'extreme' end of the relationship.

Using the broadest greenness measure, i.e. total green space, the results of this national-scale study corroborate much of the previous literature (e.g. Wolfe and Mennis, 2012; Escobedo et al., 2018; Sukartini et al., 2021) in indicating a negative relationship with violent and property crimes, i.e. greener neighbourhoods had significantly lower rates of violent and property crime (also sexual crimes, but not significantly so). Thus, the relationship reported in other countries and contexts appears to be robust in even relatively high crime contexts like in South Africa. Assuming this association is evidence of a causal link between green space and crime, this lends further credence to calls for urban greening to be a major strategy towards just and sustainable cities, not just environmentally sustainable, but also socially sustainable. It also supports calls for urban greening to be integrated into any holistic crime prevention strategies (Sukartini et al., 2021).

However, this general relationship does not necessarily hold against specific measures of green space characteristics such as tree canopy cover and proximity to public parks. In terms of the first, i.e. canopy cover, we found that while violent crime was reduced with increasing canopy cover, property crime increased. This may relate to the differing explanations of the mechanisms between crime and the extent of local greenness. In South Africa (Venter et al., 2020), as in many other countries (Gerrish and Watkins, 2018), there are marked disparities in the distribution of urban tree density and canopy according to income measures, resulting in high tree canopy cover in affluent areas and low or no canopy cover in poorer areas. Greener neighbourhoods have higher value properties and household incomes (Wüstemann et al., 2017) and consequently all the trappings and assets that typically accompany affluence which may form desired targets for robbery. However, spatial biases in crime reporting rates are often associated with neighbourhood income levels because poorer people are less likely to report crime than wealthier people (Redpath and Nagla-Luddy, 2015). Thus, we hypothesize that the higher rates of property crimes in areas with greater tree cover is a result of a combination of (i) the greater concentration of valuable assets that would be attractive to thieves, (ii) the high canopy cover providing some seclusion for criminals for opportunistic entry to properties or the hiding of stolen goods, and (iii) the bias in crime reporting rates which can make affluent areas appear more property crime-ridden than poorer areas.

We found that proximity to public parks resulted in a small, although statistically significant, increase in property crime, but had no effect on violent or sexual crime rates. Previous studies on the relationship of proximity to parks and crime have yielded contrasting results. Some have found that proximity to parks is correlated with higher rates of a variety of crime types (e.g. Groff and McCord, 2012; Kim and Hipp, 2018), although the state or management of the park influences the strength of the correlation. Well-maintained public parks, and those with one or more of fencing, lighting, playing fields and some sort of security show lower crime levels in adjacent areas than poorly maintained parks or those lacking basic facilities (Groff and McCord, 2012; Kimpton et al., 2017). The nature of the surrounding areas also influences the pattern and extent of crime (Boessen and Hipp, 2018; Taylor et al., 2019). Studies that have found elevated crime levels in or adjacent to parks interpret it as parks providing vantage points to observe adjacent properties as well as attracting visitors who represent potential targets for criminals. In contrast, some studies have found lower rates of crime in or adjacent to public or community parks as compared to streets or properties further away (Crewe, 2001), while others have found no relationships (e.g. Gorham et al., 2009). Troy and Grove (2008) showed that the broader crime situation in a neighbourhood also influences what happens in and around a park, and thus focusing specifically on a park and its immediate environs can be misleading.

Although our study was conducted at a national scale and is based on a large sample size, there are several limitations that need to be considered when interpreting the results. First, of necessity, most studies examining the relationship between urban greenery and crime rates, including ours, are correlative. As such, the studies cannot identify causation and many of the relationships are weak, even though significant, because there are multiple covariates or confounders which may or may not be included in the analysis. Here we attempt to control for confounding effects by including data on education levels, per capita income, population density and land use type. Nevertheless, we do not have sufficient data to control for all possible confounders such as numerous psychological and developmental factors (e.g. substance abuse) such as adverse childhood experiences, that are often correlated with poverty and are powerful predictors of future violence and crime (Stoddard et al., 2015). Another significant confounder we could not fully account for is land use in green spaces. Although we control for the effect of industrial/commercial, agricultural and informal settlement, we did not have data on the management, use of and quality (poor vs well-maintained) of green spaces. Formally managed parks may be less criminogenic than informal green strips that are unmaintained and overgrown. A future opportunity to overcome the limitation of confounding effects is to perform a time series analysis. Studies of change in crime rates following some change in greenness do not suffer from the drawbacks (i.e. confounding effects) of spatial correlation studies and may be an avenue for research in South Africa. For example, Sukartini et al. (2021) found that rates of crimes declined in urban wards in Indonesian cities after development of an urban park in the ward, and the opposite occurred when urban parks were removed. Similarly Kondo et al. (2017) reported increases in crime rates following the removal of street trees in the US as part of efforts to control the spread of emerald ash borer.

A second limitation of our study is that the crime rate data are expressed on a per 100,000 people basis which requires reliable and up to date data on population numbers. However, the last national census in South Africa was in 2011 and because South Africa is experiencing rapid urban growth (due to both rural to urban migration and internal growth), the population data are out of date for some rapidly changing areas. This will therefore influence the crime rate data and relationships for some specific sites; but is unlikely to affect the overall models due to the high number of points ($n = 1152$). A final limitation in our analysis is the potential reporting bias in crime records for police precincts. This reporting bias is both a product of under-reporting of certain types of crime (e.g. sexual) and spatial variation in reporting rates where people in affluent, treed areas are much more likely to report property crimes (for insurance purposes) than those living in poorer, less treed areas, with little to no insurance or incentive to report the crimes (Tarling and Morris, 2010). Furthermore, crime statistics from certain regions of South Africa, including the Eastern Cape and KwaZulu-Natal, may be biased due to the fact that some crimes are dealt with by traditional authorities and not reported to the police (Tshehla, 2005). We were unable to assess regional differences in associations between crime and green space due to the limited number of precincts per region which decreases statistical power.

The limitations discussed above are common to many spatial analysis of crime and green space distribution (Shepley et al., 2019), and point to needs for future research that will better inform policy and planning revisions. We identify a number of avenues for further research including (i) an examination of the causal mechanisms underlying the relationships revealed in this study, (ii) if, how and why the relationships vary through time, (iii) how public perceptions that trees and greenery promote crime (by providing hiding spaces for criminals) can be addressed, (iv) how the ownership, management and use of different green spaces facilitates or mitigates criminal activity, and (v) how crime reporting rates vary across crime categories and over space leading to biases in the apparent association with green space. Finally, due to the large variation in the green space-crime associations in our study, we recommend that future studies should either include a wide range of crimes and greenness measures (as many already do), or provide very clear motivations for the selection of only a subset of either.

5. Conclusions

A core finding from this study is that the relationships revealed were not uniform across crime types and across different measures of neighbourhood greenness. While total green space is associated with less property and violent crime, tree canopy and proximity to parks is associated with more property crimes. Overall, this study contributes a Global South perspective to the growing body of knowledge showing that increasing urban greening generally is correlated with lower crime rates. However, it also points towards the need for more research on factors that may confound the association between crime and green space.

Our findings provide a nuanced but crucial message in a country like South Africa, which is experiencing rapid urban growth and generally high crime rates by international standards. These results add further impetus to arguments for urban planners and decision-makers in South Africa and similar contexts to be more proactive and ambitious in including and integrating urban green spaces into urban developments. Such calls are frequently down-played by planners and authorities because they are viewed as emanating from an environmental lobby, and because it is perceived that they require trade-offs with pressing economic and social development needs (Gwedla and Shackleton, 2015). However, this research, and others like it, highlights that benefits of urban greening extend well beyond just an environmental agenda, to embrace social inclusivity and sustainability too, alongside the well-established public health benefits. Hence, urban greening needs to be one of the foremost considerations in urban planning and development in the country, which is currently not the situation (Gwedla and Shackleton, 2015; Venter et al., 2020). This requires a revision of urban planning guidelines and requirements. It also requires budgets, expertise and strategies beyond just the planning phase to allow for regular tree and green space maintenance that keeps them functional and attractive to local citizens, to avoid the possibility of them becoming spatial nodes of criminal activity as opposed to pleasant environments that promote citizen's health, wellbeing and safety.

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CRediT authorship contribution statement

Zander Venter: Conceptualization, Methodology, Writing-Original draft preparation. Charlie Shackelton: Writing-Reviewing and editing. Andrew Faull: Writing-Reviewing and editing. Lizette Lancaster: Data curation, Writing-Reviewing and editing. Gregory Breetzke: Data curation, Writing-Reviewing and editing. Ian Edelstein: Writing-Reviewing and editing.

Declaration of competing interest

We declare no conflict of interest for the publication entitled “Is green space associated with reduced crime? A national-scale study from the Global South”.

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