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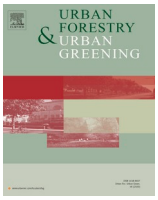

Can restoring vacant lots help reduce crime? An examination of a program in Baltimore, MD

Anton Kvit [a,*], Anne E. Corrigan [a], Dexter H. Locke [b], Frank C. Curriero [a], Kristin Mmari [c]

[a] Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States
[b] USDA Forest Service, Northern Research Station, Baltimore Field Station, Baltimore, MD, United States
[c] Department of Population, Family, and Reproductive Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States

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ABSTRACT

Urban green spaces have previously been linked to reduction in crime and improvements in neighborhood environments. This study considered if the Care-A-Lot (CAL) program in Baltimore City, which incentivizes local community groups to maintain and green vacant lots, reduces violent and property crime. Compared to a 2016–2017 baseline, city block groups with CAL programs saw a significantly larger decrease in crime compared to matched block groups with no CAL programs both in 2018 and 2019. These results were found to be robust through a series of sensitivity analyses and add to the literature stressing the positive social impact of green spaces.

1. Introduction

The presence of green space is viewed as a key health-promoting characteristic of residential environments, and has been linked to reductions in stress, violence, aggression, and crime, as well as improvements in neighborhood social cohesion and self-reported health (Cohen et al., 2008; Garvin et al., 2013; James et al., 2015; Vanaken and Danckaerts, 2018). For example, a health impact assessment in Philadelphia estimated that 403 premature deaths could be prevented if the city achieved its 30% tree canopy goal (Kondo et al., 2020). Given that low-income communities often have less access to quality green spaces (Nesbitt et al., 2019a, 2019b; Watkins and Gerrish, 2018) or more exposure to poorly maintained, vandalized, or unsafe green spaces (WHO, 2012), a number of cities have established programs that focus on vacant lots to address urban blight and crime. These programs involve greening and restoring vacant lots, which typically includes debris removal, mowing grass, planting trees and grass, and sometimes installing fencing and gardens (BMORE Beautiful, 2018; Gilstad-Hayden et al., 2015; Locke et al., 2017). A recent meta-analysis of eight before-and-after studies with a control group showed greening and gardening interventions reduce firearm violence by ~5%, and more data could help refine cost-benefit estimates (Sadatsafavi et al., 2022). Indeed, there is a greater need to demonstrate the public-health benefits of urban greening and stewardship, especially when justifying funding for municipal programs (Donovan, 2017).

While these restoration efforts are believed to improve the aesthetics and physical attributes of low-income neighborhoods, recent studies have shown that restoring vacant lots may also improve the health of nearby residents (Branas et al., 2018; Kondo et al., 2016; Kuo and Sullivan, 2001; South et al., 2018). In Philadelphia, a randomized control study showed that removing trash and debris, planting new grass and trees, and installing fences to create a park-like setting were associated with a 29% reduction in gun violence and over a 40% reduction in depressive symptoms among adult residents who lived near the restored lots (Branas et al., 2018; South et al., 2018). Similarly, in Youngstown, OH, researchers found an 85% reduction in felony assaults, 24% reduction in burglaries, and a 69% reduction in robberies, within a 1/8-mile radius of restored vacant lots compared to unmaintained vacant lots (Kondo et al., 2016). Despite this growing body of evidence, however, the research on the impact of greening is still limited, especially with approaches including no-treatment control groups or comparing pre- and post-greening intervention outcomes.

Vacant lot restoration and stewardship may be particularly relevant for reducing crime and violence in Baltimore City, which has one of the highest homicide rates among large cities in the United States (Phalen et al., 2020; Sutherland et al., 2021). Currently, there are over 18,000

* Correspondence to: Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, 627 North Washington Street, 2, Baltimore, MD 21205, USA.
E-mail address: akvit1@jhu.edu (A. Kvit).

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vacant lots and an additional 17,000 abandoned buildings in the City. As the root causes of crime and violence are complex in Baltimore and include factors such as inter-generational trauma; structural racism; lack of economic opportunities; and systemic underinvestment of youth, families, and neighborhoods, a variety of different violence preventions strategies are necessary to address these broad range of factors – including implementing place-based strategies which target violence in the contexts in which they occur.

There are several different theories that explain why place-based strategies, such as restoring vacant lots, leads to reductions in crime. One such theory is the 'broken windows theory' which posits that visible signs of neglect and poor maintenance (signs of physical disorder) signal that an area is uncared for by its residents, and this makes it vulnerable to criminal activity (Garvin et al., 2012). Therefore, when vacant lots are restored and cared for, and signs of neglect and disorder are reduced, criminal activity should also be reduced. Certain landscapes signal greater human "cues to care" or acts of human intention (Li and Nassauer, 2020; Nassauer, 1995, 1988). Cues to care may be thought of as applying a broken windows theory to landscaping, and vacant lot stewardship and greening by residents has been associated with reduction in crime in Chicago (Hadavi et al., 2021). Another theory, called the 'busy streets theory,' reframes the focus away from physical disorder and instead predicts that engaging residents in physical revitalization of neighborhoods will facilitate community empowerment through the development of sense of community, social cohesion, and behavioral action. The theory further suggests that resident's engagement in physical revitalization activities will create organized neighborhoods that signal ownership and invite positive social interactions that subsequently leads to reductions in crime (Rupp et al., 2020). While more research is needed to test these theories to understand the mechanism behind vacant lot stewardship and crime reduction, there are also substantial uncertainties about which types of urban greening are associated with the greatest reductions in crime, when, and where (Wolf et al., 2015). Roughly 8–21% of vacant lot greening program costs can be offset by the reduction in firearm violence alone, which does not include the co-benefits greening and improvement in health, mental health, increases in tax revenue, reductions in flooding, and mitigating the urban heat island effect (Sadatsafavi et al., 2022).

In an effort to reduce the prevalence of urban blight in the City, Baltimore City's Office of Planning has created a *Green Network Plan* to restore all vacant lots in targeted neighborhoods with high concentrations of vacancy. As part of this Plan, the Care-A-Lot (CAL) program is the formal city-run initiative which partners with community groups to clean, maintain, and beautify vacant lots in Baltimore. Launched in 2014, CAL provides grants of up to $5500 to various community-based organizations to handle up to 25 vacant lots during the greening season which lasts from May to October. Funds are dispersed through an invoice process, paid at $22 per lot visit for up to 10 visits during the greening season, and grant awardees must visit the selected lots at least once every three weeks. The types of lot restoration efforts vary, ranging from basic landscaping and lawnmowing to building community gardens, farms, and creating community gathering spaces. Participating organizations include youth groups, nonprofits, community associations, and community development corporations. While crime reduction is not the primary goal of the CAL program, promoting safe neighborhoods is listed as one of the aims (BMORE Beautiful, 2018), and measuring the extent to which this is possible through CAL implementation is of great interest.

The present analysis was conducted to evaluate the efficacy of the Care-A-Lot program in reducing crime in Baltimore City, as well as to contribute to a broader literature studying the relationship between lot stewardship, such as greening and gardening, and crime. Few previous studies investigate interventions over time or study the relationship between specific vacant lot greening programs and crime (eight were identified by (Sadatsafavi et al., 2022). The purpose of this study is to examine whether and to what degree Census block groups with vacant lots stewarded by participants in the Care-A-Lot program are associated with differences in crime, relative to block groups with similar real estate markets, but without Care-A-Lot vacant lots.

2. Methods

2.1. Crime and exposure measures

Census block groups were the unit of analysis to examine the association between vacant lot stewardship and hypothesized reductions in crime. Only block groups with more than 50 residents were included, reducing the number of block groups considered from 653 to 646. Of these, 88 geographically intersected with at least one Care-A-Lot in 2018 or 2019.

Crime density was aggregated from point locations and calculated as crimes per square kilometer for each Census block group. In order to correspond with the lot stewardship season as well as the highest crime season ("Open Data | Baltimore Police Department," 2020), only crimes which occurred from June to August were considered. Locations of violent (Aggravated Assault, Common Assault, Homicide, Rape, Shooting) and property (Auto Theft, Arson, Burglary, Larceny, and Robberies) crimes that took place in the city of Baltimore between 2016 and 2019 were obtained from the Baltimore Police Department ("Open Data | Baltimore Police Department," August, 2020). Crime densities measured in 2016 and 2017 were averaged for each block group and considered as a baseline measure. This strategy provided a stable two-year summary of crime in Baltimore City prior to Care-A-Lot program formalization while avoiding the 2015 Baltimore uprising and a subsequent uptick in crime and violence, which was primarily due to the arrest of Freddie Gray and his subsequent death from injuries sustained while in police custody ("Charts: Baltimore Crime, Before And After Freddie Gray's Funeral | FiveThirtyEight," 2015; White et al., 2018, August, 2020). Differences in crime density between 2018 as well as 2019 and the 2016/2017 baseline were calculated as the dependent variable for this analysis.

The Care-A-Lot (CAL) program, run by the Baltimore City Department of Public Works, provided the locations and descriptions of vacant lots which were funded for CAL stewardship in 2018 and 2019. A total of 421 lots were managed in 2018 and 549 in 2019. Funding from the CAL program supported groups from May to October, but most stewardship activities took place between June and August. Care-A-Lot density was calculated as the proportion of the block group area which was stewarded under the Care-A-Lot program. The data provided on the vacant lots stewarded by participating residents used parcel addresses, and thus multiple adjacent vacant lots were recorded as separate legal entities, even though they functionally operate as a single cohesive greenspace. The proportion of the block group area stewarded by CAL participants was chosen as the primary exposure metric, rather than the number of CAL lots per block group, because lot sizes do vary. However, counts per block group were also evaluated in a sensitivity analysis. The Care-A-Lot program provided a rating of lot quality, which was also examined as part of a sensitivity analysis.

Median residence sales price as well as vacant land (and vacant residential buildings) as percent of land area in each block group was obtained from the City of Baltimore Department of Planning for all Census block groups in Baltimore for Q3 2015 through Q2 2017 (Baltimore City Department of Planning, 2017). These variables were used as covariates in subsequent Care-A-Lots on crime regressions since block groups at different socioeconomic levels have differing crime rates, Care-A-Lot densities, and potential for improvement from lot stewardship. Prior to the regression analysis including all 646 block groups considered in this study, 88 of which included at least one Care-A-Lot, Rosner's outlier test was utilized after studying the data. The test identified two significant outlier block groups, one with an unusually high crime density increase in 2019 compared to baseline, and the other with a particularly high (7.4%) proportion of land area taken up by Care-A-Lots (Fig. S1). These block groups made up $<$ 1% of all

observations in the analysis and were removed from the study due to their outlier status, leaving 644 block groups in the study.

In order to determine how Care-A-Lots and crime associate in a socioeconomically consistent environment, the residence sales price and vacant residential land percent were also used to exclude high property value block groups with low vacancy from the analysis via 1:2 Mahalanobis matching. The result was a subset of 262 block groups of similar socioeconomic background which was used in a sensitivity analysis. The presence of an increased policing and enforcement program called the Violence Reduction Initiative (VRI, https://www.baltimoresun.com/maryland/baltimore-city/bs-md-ci-transformation-zones-20180308-story.html), as also examined in the sensitivity analyses.

2.2. Statistical analyses

Multivariate linear regression models controlling for median residence sales price and the percent of vacant land and building area were applied to the entire dataset to estimate the association between change in crime density from the 2016/2017 baseline with CAL areal proportion in 2018 and 2019 (Eq. 1). Additionally, violent and property crimes were analyzed separately. A negative coefficient value corresponded to a decrease in crime density.

$$\Delta crime = \beta_0 + \beta_1 CAL\ proportion + \beta_2 Residence\ Price + \beta_3 Vacant\ area\ percent + residual \quad (1)$$

Spatial dependence of crime density difference from baseline was explored using Moran's I correlograms to determine whether similar changes tend to occur in nearby block groups. A binary queen adjacency spatial weight matrix defined the neighborhood structure, and the correlogram plotted similarity as a function of spatial lags (neighbors of neighbors). After regressions were completed, the residuals were also assessed for spatial dependence using Moran's I to see whether CALs helped account for any spatial dependence originally found in the crime density difference, and Lagrange multiplier test was used to guide the selection of an appropriate model specification.

Next, we conducted a number of additional regression analyses to test the robustness of our findings and evaluate our definitions for the exposure and outcome of interest. First, regressions on the 262 block group socioeconomically similar dataset were also conducted, without controlling for residence sales price and percent vacant area, since these variables were already utilized in subsetting the data. Third, in an effort to determine whether counting the number of lots versus area of all lots in a block group (the association with lot size) might have a different associate with crime, the number of individual CAL parcels within each block group was used as the independent variable (Eq. 2).

$$\Delta crime = \beta_0 + \beta_1 CAL\ number + \beta_2 Residence\ Price + \beta_3 Vacant\ area\ percent + residual \quad (2)$$

To investigate the variation in lots' level of care, a quality estimate was calculated for each lot ranging from 0 to 4, with 1 point each assigned for having additional funding beyond the Care-A-Lot program, additional care beyond CAL minimum maintenance requirements, known care preceding CAL involvement, and workforce development programs onsite (Eq. 3). Study investigators hypothesized each of these elements would increase the degree of impact (greenspace improvement/crime reduction) in a potentially additive fashion. The four categories were created and scored by the community program liaison and data manager for the CAL Program based on qualitative surveys and historic information provided by community leaders (recipients of CAL funding). These quality scores for all lots in a block group were averaged and considered as a covariate to control for lot quality.

$$\Delta crime = \beta_0 + \beta_1 CAL\ proportion + \beta_2 CAL\ quality + \beta_3 Residence\ Price + \beta_4 Vacant\ area\ percent + residual \quad (3)$$

To explore the potential relationship between CAL proportion and crime in neighboring block groups, average CAL proportion in block groups sharing a border with the block group of interest was included as a covariate in another sensitivity analysis (Eq. 4). To determine whether existing parks and green spaces might affect the relationship between CALs and crime density, the areal proportion of parks within each block group was also considered in regression modeling (Eq. 5).

$$\Delta crime = \beta_0 + \beta_1 CAL\ proportion + \beta_2\ neighbor\ CAL\ proportion + \beta_3 Residence\ Price + B_4 Vacant\ area\ percent + residual \quad (4)$$

$$\Delta crime = \beta_0 + \beta_1 CAL\ proportion + \beta_2\ park\ proportion + \beta_2 Residence\ Price + \beta_3 Vacant\ area\ percent + residual \quad (5)$$

Finally, the proportion of each block group taken up by a Violence Reduction Initiative (VRI) zone since was considered as an additional covariate to explore the effect policing interventions in Baltimore might have on the outcomes. (Eq. 6).

$$\Delta crime = \beta_0 + \beta_1 CAL\ proportion + \beta_2\ VRI\ proportion + \beta_2 Residence\ Price + \beta_3 Vacant\ area\ percent + residual \quad (6)$$

Initial regressions included crime density outcomes, CAL proportions, as well as residence sales price and vacant area percent, while the subsequent analyses considered lot quality, neighboring CAL proportion, and park proportion as individual additional covariates in separate regressions. Equations outlined above specifying regression model structure were each applied three times in the analysis, for changes from baseline to 2018, change from baseline to 2019, and change between 2018 and 2019. Spatial data management and statistical analysis for this study were done using R statistical software (version 3.6.1) and ArcGIS Pro software (version 10.6).

3. Results

Population density and median home sales prices were lower in block groups with CALs, and vacancy, crime, and changes in crime were greater (Table 1). Block groups with CALs were primarily found in West and East Baltimore and covered a range of crime densities. An increased crime density in Central, West, and East Baltimore was also apparent (Fig. 1).

Land area proportion of each block group occupied by CALs was considered as the primary independent variable in this analysis, on average covering about 1% of a given block group with CALs (Fig. 2). Change in crime density compared to the 2016–2017 baseline varied from − 119.6–163.5 crimes per km^2 in 2018 and between − 94.1 and 376.3 crimes per km^2 in 2019 (Fig. 2). While similar direction and magnitude of density changes were often found in neighboring block groups, substantial differences were observed in some neighboring block groups as well.

Baseline crime density (2016–2017 average) was 131.4 crimes per km^2 in block groups with Care-A-Lots, 73.4 crimes per km^2 in block groups without CALs, and 87.2 crimes per km^2 in Baltimore overall. In block groups with CALs, crime density decreased by 13.9 per km^2 from baseline in 2018 and 24.8 crimes per km^2 in 2019, which was a larger decrease than in block groups with no CALs (2.7 and 4.1 crimes per km^2 in 2018 and 2019 respectively) as well as all Baltimore block groups (3.4 and 4.8 crimes per km^2 in 2018 and 2019 respectively) (Table 1). There were 62 block groups with CALs in 2018, with CAL lots making up an average of 0.8% of the total block group area, and 75 block groups with CALs in 2019, making up 0.9% of the block group area on average (Table 2).

Based on the linear regression analysis, there was a decrease in 16.9 crimes per km^2 ($p < 0.01$) from the 2016–2017 average baseline to 2018 associated with one percent increase in Care-A-Lot areal proportion by block group; meanwhile, from baseline to 2019, there was a decrease of 14.7 crimes per square kilometer ($p < 0.05$) per unit increase in CAL proportion. The change in crime density from 2018 to 2019 was not

Table 1
Characteristics of block groups with Care-A-Lots in 2018 or 2019 compared to block groups with no Care-A-Lots, as well as all block groups in Baltimore City. Median and interquartile range (IQR) of the total population, variables used in the matching process, and variables relevant to crime density outcome. Baseline crime density is the average of 2016 and 2017 values.

	All Baltimore Census Block Groups (n = 644)		Block Groups without Care-A-Lots (n = 556)		Block Groups with Care-A-Lots (n = 88)	
	Median	IQR	Median	IQR	Median	IQR
Total Population	835	552	866	559	769	460
Median Home Sales Price, 2017 (USD)	65,000	107,539	75,087	124,327	18,320	28,369
Percent of Vacant Buildings, 2017 (%)	2.52	9.16	1.95	6.01	14.31	13.58
Crime Density: all crimes per square km						
Baseline	87.21	118.34	73.4	106.8	131.36	95.15
2018	80.9	112.87	70.31	107.64	120.76	89.24
2019	78.1	115.33	69.53	104.42	113.81	83.42
Change: 2018 - baseline	-3.36	39.01	-2.67	34.98	-13.86	70.11
Change: 2019 - baseline	-4.78	41.20	-4.08	37.39	-24.79	57.19

significantly associated with the change in CAL proportion over the same period.

Looking at violent crime separately, a significant ($p < 0.05$) decrease of 8 crimes per km^2 for every percent increase in CAL proportion was seen between 2018 and baseline, but no significant associations were observed for 2019 crime density difference from either the baseline or 2018 (Table 3). With property crimes, a marginally significant ($p = 0.073$) decrease of 8.8 crimes per km^2 for every percent increase in CAL proportion was seen from baseline to 2018, and a significant ($p < 0.05$) decrease of 9.8 crimes per km^2 was observed in 2019 compared to baseline. No significance was identified in the association of CAL proportion and 2019–2018 property crime difference.

Regressions including outliers and considering the number, rather than areal proportion of Care-A-Lots were conducted as sensitivity analyses to ensure the robustness of these findings. Linear regressions including the two outlier block groups removed from the primary analysis showed that from baseline to 2018, for every percent increase in Care-A-Lot proportion within a block group, total crime density decreased by 15.3 crimes per km^2 ($p < 0.05$), indicating a greater crime reduction in block groups with more CALs. Change in crime density in 2019 from baseline was not significantly associated with CAL proportion. However, between 2018 and 2019, for every percent increase in CAL proportion, there was an increase of 19.1 crimes per km^2 ($p < 0.01$) in total crime (Table S1). Considering the number of Care-A-Lots per km^2 rather than Care-A-Lot areal proportion as the primary independent variable resulted in findings that were similar to the principal coefficient of interest.

Average lot quality measures were not significantly associated with crime and did not substantially alter the reported CAL proportion associations (similar in magnitude and same interpretation of significance). Controlling for percent area of other park and green space by block group or controlling for CAL areal proportion in neighboring block groups (spatial lags) in multivariate regressions did not alter the associations identified in the primary analysis with the exception of one variation. The average Care-A-Lot proportion in neighboring block groups was found to be marginally ($p < 0.076$) associated with a decrease in crime in 2018 compared to baseline. Regressions using the 262 block group subset with similar socioeconomic backgrounds produced results that were very similar to the primary study outcomes (Table S2). Outcomes did not substantially change when VRI zones were considered as covariates in the analysis (Table S3).

The baseline to 2018 crime differences showed slight spatial dependence when assessed via a Moran's I correlogram, and this was not explained by CAL proportion, since the regression model residuals showed similar slight spatial dependence (Fig. S2). Since this identified spatial dependence was marginal, it was not expected to bias the study results. Lagrange multiplier diagnostics did not indicate significant spatial dependence of the residuals.

4. Discussion

The results of this study are consistent with previous literature (Branas et al., 2018; Gilstad-Hayden et al., 2015; Kondo et al., 2016; South et al., 2018) which shows that vacant lot stewardship is associated with reduction in nearby crime. In our study, compared to the 2016–2017 baseline, the most significant reduction occurred the following year, in 2018. While crime rates stayed significantly lower than the baseline in 2019, there was no further reduction in crime density between 2018 and 2019, suggesting that the introduction of Care-A-Lots had the most significant crime-reducing association, and that association was sustained, but not augmented, in the following year. While this pattern occurred when two outlier block groups were removed, retaining them in the analysis still resulted in a significant reduction in crime after CAL implementation, though crime rates returned to near-baseline in the following year. However, since this pattern was driven by only 1% of block groups (2 outliers), it was not deemed as representative for the entire study area. It is evident that in most cases, crime reductions were maintained across both years of the study.

Statistically significant 8.0–16.9 fewer crimes per km^2 in crimes were related to the proportion of Care-A-Lots in a block group (Table 3) Given the average number of crimes per block group, this is a regression-adjusted estimate of 5–11% fewer crimes. This is on par with ecological studies like the one conducted by Gilstad-Hayden in 2015 in New Haven, CT (Gilstad-Hayden et al., 2015) that considered how crime rates are associated with tree canopy cover at the block group level, and found that a 10% greater tree canopy within a block group was associated with 15% lower violent crime and 14% lower property crimes. A 2012 study (Troy et al., 2012) in Baltimore City and county that found that 10% greater tree canopy was associated with 12% lower crime at the block group level. Unlike these studies, the present analyses looked at crime change, rather than a cross-sectional snapshot and lot interventions that went beyond only greening efforts. As a result, they may not be compared directly. However, the same negative direction of the association between crime and greening and a comparable reduction in crime rates further supports the presented findings.

Though other research has argued for the use of block faces (Lacoe and Ellen, 2015; Locke et al., 2017) or radial buffers independent of any geographic unit in urban analysis, Census block groups were used as the unit of analysis in this study for a number of reasons. Block groups are a widely accepted geographic unit used by researchers (Gilstad-Hayden et al., 2015; Troy et al., 2012) and policymakers. Thus, providing study

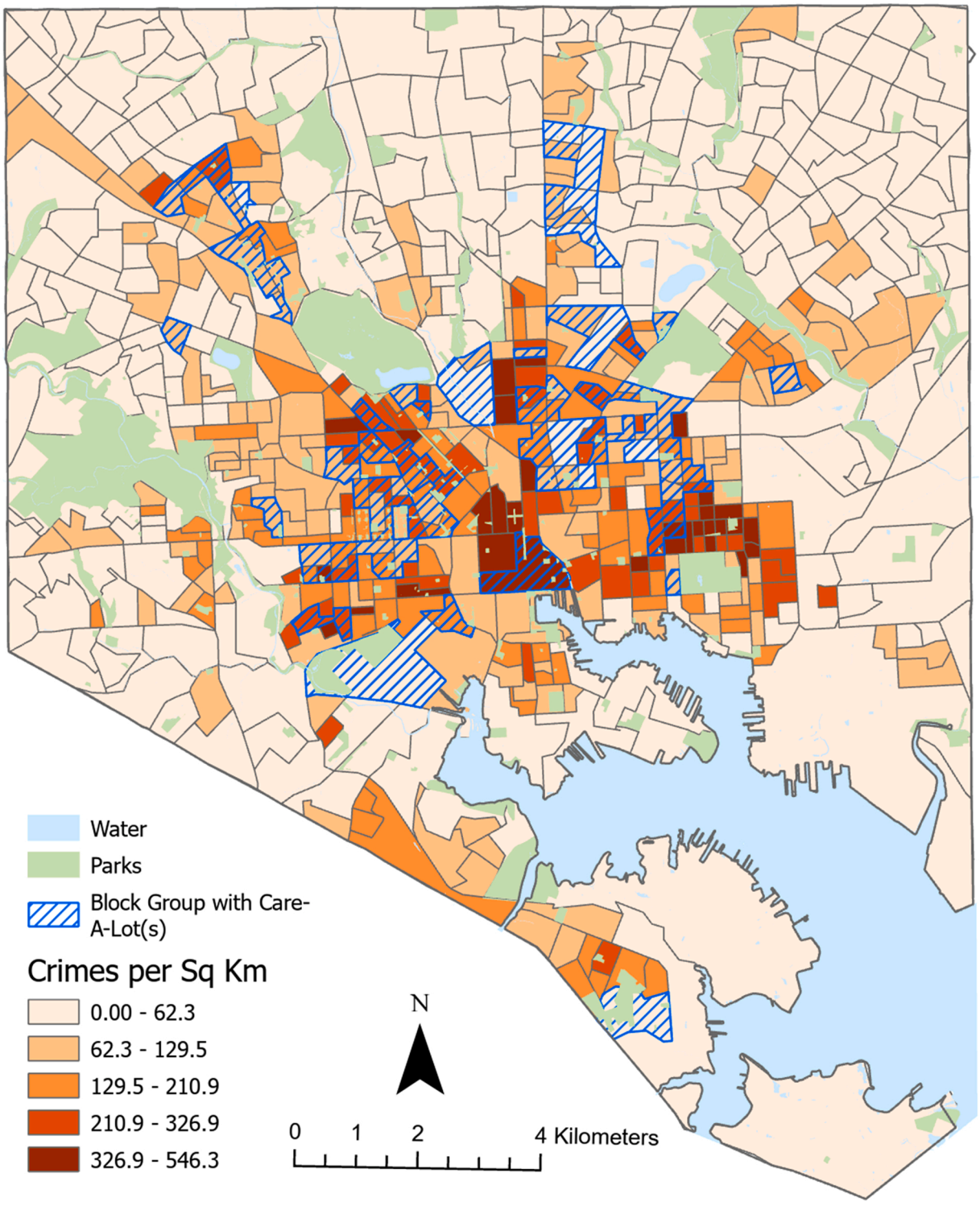

Fig. 1. Baseline crime density (number of total crimes per square kilometer) across Baltimore City block groups. Baseline crime density is an average of crime density in 2016 and 2017 based on all types of crime which occurred during June, July, and August.

results by block group makes the findings easier to compare to other crime intervention methods and community efforts. Aggregating both CAL proportions and crime densities to block groups allowed us to resolve issues that arise from direct spatial measures, including double-counting crime that occurs near multiple lots, or accounting for the potential impact that several neighboring lots might have. Furthermore, variables used in the study design including residence sales price, housing vacancy, and total population were available only at the block group level. Finally, Branas et al.,(2018) found that block group analysis of vacant lot greening lead to similar results when considering either block group aggregation of boundary free analysis. Therefore, while block group aggregation somewhat reduced the spatial resolution of this study, it was still considered to be appropriate.

One way to examine the benefit of this place-based intervention is to compare it with other types of interventions that have been implemented in Baltimore City to reduce crime. One such program, for

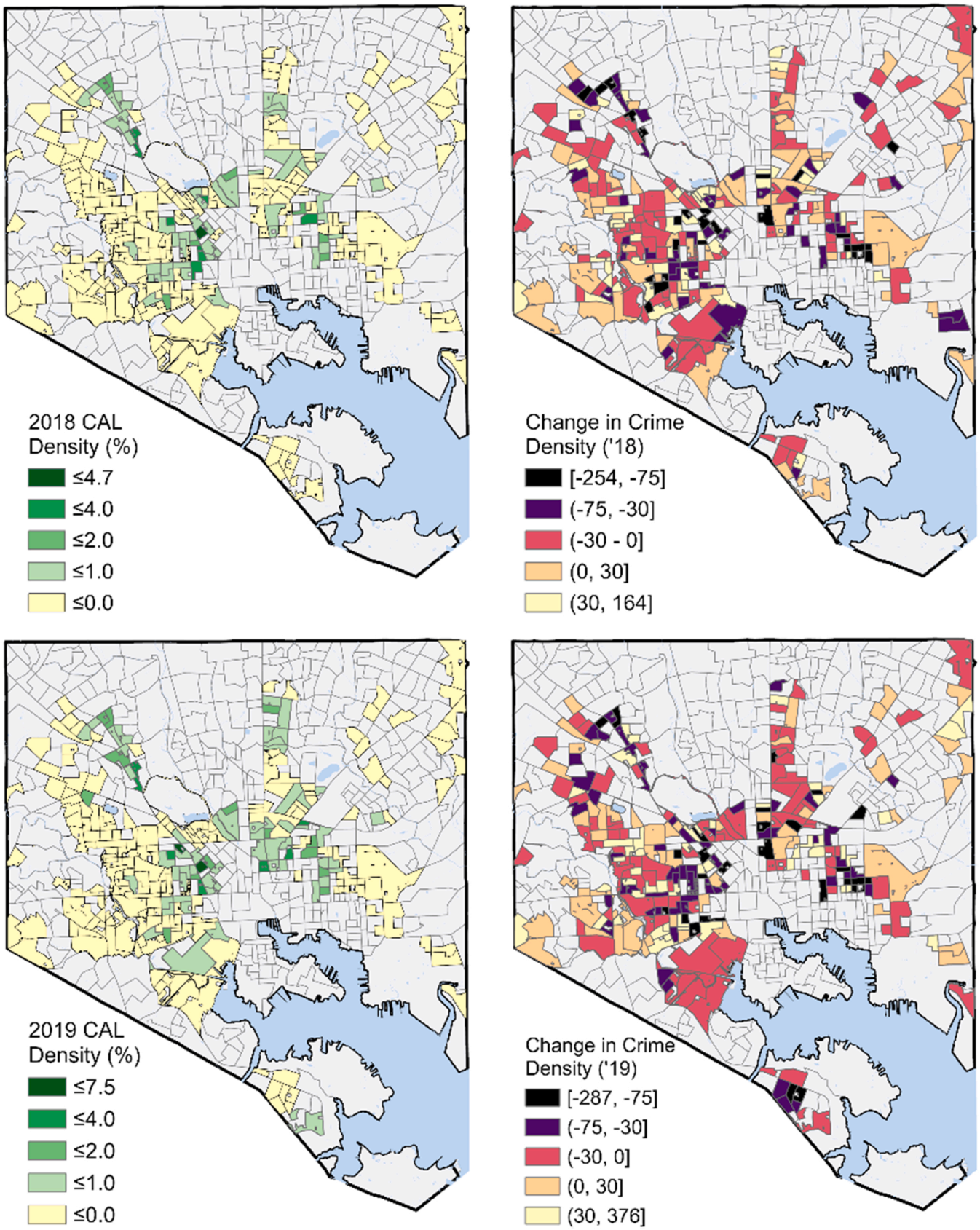

Fig. 2. Change in crime density in block groups in 2018 and 2019 relative to the 2016–2017 baseline. Change in crime density from baseline to 2018 or 2019 was calculated such that a positive value represents an increase in crime density over time.

Table 2
Summary statistics of stewardship efforts for block groups with Care-A-Lots in 2018 or 2019.

	2018	2019
Total block groups with Care-A-Lot(s)	62	75
Percent of Land Area with Care-A-Lot		
Minimum	0.001%	0.001%
Median	0.59%	0.65%
Mean	0.84%	0.85%
Maximum	3.43%	3.53%

Table 3
Linear regression results of crime density difference from baseline on Care-A-Lot proportion controlling for residence price and vacant lot percent. Total crime, violent crime, and property crime is considered.

Crime Type	Variable	Coefficient (95% C.I.)	P-value
Total	2018 Difference from Baseline	-16.9 (−28.3, −5.4)	**0.004**
Total	2019 Difference from Baseline	-14.7 (−25.3, −4)	**0.007**
Total	2019 Difference from 2018	-3.2 (−14.6, 8.3)	0.587
Violent	2018 Difference from Baseline	-8 (−14.3, −1.8)	**0.013**
Violent	2019 Difference from Baseline	-4.8 (−12, 2.3)	0.187
Violent	2019 Difference from 2018	0.1 (−7.9, 8)	0.986
Property	2018 Difference from Baseline	-8.8 (−18.5, 0.8)	0.073
Property	2019 Difference from Baseline	-9.8 (−18.3, −1.3)	**0.024**
Property	2019 Difference from 2018	-3.2 (−12.1, 5.6)	0.472

example, is the Violent Crime Impact Section (VCIS) program that operated from 2007 to 2012 in some neighborhoods and resulted in an overall 12–13% reduction in homicides and 32% reduction in non-fatal shootings over that time (Webster et al., 2018). Reducing alcohol outlet density by a quintile was also found to be associated with approximately 17% reduction in yearly homicides, and removing liquor stores in residential zones was associated with a about a 7% reduction in homicides (Trangenstein et al., 2020). While a direct comparison of such different interventions is not appropriate, the reductions of 5–11% that we identified are on par with other types of intervention methods, indicating that lot stewardship could be considered as an important component of crime reduction strategy.

Violent and property crime responses to CAL stewardship were not substantially different, though the reduction in 2019 violent crime compared to baseline was no longer significant, unlike property crime and crime overall. Previous studies (Garvin et al., 2013; Kondo et al., 2016; Locke et al., 2017) have identified similar rates of reduction in violent and non-violent crime as a result of stewardship, while others found some differences. Li observed that view-blocking vegetation was associated with more violent crime but less property crime (Li, 2008), while Kondo and colleagues (Kondo et al., 2016) found that lot stabilization treatment was more associated with property crimes, while the community reuse was associated with a reduction in violent crimes. Since the analysis presented here does not consider the type of stewardship intervention, further work needs to be done to identify whether true substantial differences exist in violent and property crime responses to lot interventions.

No significant association was found between crime and lot quality, however, this might be due to the limited 0–4 score system, since the components going into the score were rough approximations based on limited available information, rather than objective measures. A more thorough scoring system based on stewardship intervention type and progress consistently tracked over time as well as a comprehensive pre-CAL intervention history would provide a significantly improved lot quality measure. While proportion of block groups taken up by parks was not significantly associated with crime in this analysis, some parks have been found to attract crime in Baltimore (Troy et al., 2008), so park proximity will continue being an important covariate in future studies.

CAL proportion in neighboring block groups was not found to significantly associate with crime difference, though the marginal significance in 2018 compared to baseline suggests that lot stewardship might influence the surrounding block groups as well. Further study is required to explore the potential variation or nuance in the geographic range of the lot stewardship effect.

Several important limitations exist in the presented analysis, including lack of information on other stewardship efforts, a limited temporal scale, and non-random CAL distribution. Most importantly, CAL data was not available prior to 2018 though some stewardship activities were likely already happening. Based on the presented results we hypothesize that longer, multi-year interventions are likely to maintain a positive impact, and thus more work in the future will be dedicated to long-term analyses as more data becomes available. Since the most substantial decrease in crime (Table 3) occurred in 2018, right after official CAL implementation, we expect that most significant crime reductions occur during the initial stewardship effort. Therefore, while pre-existing stewardship could bias the presented results, it is likely to artificially diminish the crime reduction association that we saw, and true crime reduction is even more significant when stewardship occurs for the first time. Similarly, other stewardship programs with unavailable (yet to be harmonized) data exist in Baltimore that were not considered in this analysis. This limitation highlights the great importance of thorough documentation of lot stewardship or any other community projects, since without it, proper impact evaluation is impossible, greatly hindering sustainability and resource allocation for these projects in the long run. Future work will be conducted to create a thorough historical and geographic registry of lot stewardship in Baltimore City to account for this issue in subsequent studies.

This study focused on crime occurring between June and August, at the same time as the CAL stewardship activities. While this provided us with evidence that crime reduction occurs as lots are actively maintained, long term impacts of stewardship, including time periods when lots are not being maintained, also need to be studied. While crime data from 2015 was excluded from this study due to a crime spike during the Baltimore uprising as a result of the death of Freddie Gray, other events and police interventions might have influenced crime and crime reporting, potentially introducing unaccounted bias.

Finally, Care-A-Lot locations were not selected at random but rather were identified by stewards based on various criteria and convenience. Neighborhood conditions that resulted in CAL selection could influence crime rate changes as well. While this potential bias is important to consider, controlling for socioeconomic variables as well as subsetting the data to block groups with similar socioeconomic conditions using Mahalanobis matching allowed us account for some of it. While we did not conduct a direct paired analysis, future studies could use a similar subsetting approach to identify the optimal counterfactual block group for every block group with CALs and to study factors affecting crime rate changes more precisely.

The City's Care-A-Lot Program and other Baltimore lot stewardship initiatives are not yet equipped to evaluate the variability in stewardship or local community engagement and address other identified limitations, however, additional research is currently underway to gather data across stewardship efforts to examine these associations in greater detail and understand how these types of interventions can best be implemented. Meanwhile, the presented study adds to the body of literature that supports lot stewardship as a component in city crime-reduction efforts. Currently, about 17% of the land in US cities is vacant, which is the consequence of industrial decline and disinvestment in medium and large cities that began in the mid-twentieth century (Garvin et al., 2012). Our study suggests that interventions like the CAL program may not only improve the visible landscape of urban vacancy, but also improve residents' sense of safety by reducing crime and violence. The findings of this study are timely as a reckoning with crime and policing across the country has called for new and effective strategies to prevent and reduce violence. Moreover, applying vacant lot stewardship as a crime reduction strategy has strong potential for additional public health benefits including improved individual health, community social

cohesion, neighborhood beautification, and ecosystem services which traditional crime reduction approaches lack. In conclusion, this work provides evidence that structural, place-based programs can significantly reduce crime, emphasizing that stewardship efforts have the potential to be high impact interventions for improving the health of residents who live near such efforts.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Anton Kvit reports financial support was provided by Bloomberg American Health Initiative.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2022.127630.

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