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Associations between greenspace and mortality vary across contexts of community change: a longitudinal ecological study

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► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/jech-2019-213443).

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Received 1 November 2019
Revised 7 February 2020
Accepted 10 February 2020

ABSTRACT

Background Concerns about loss of greenspace with urbanisation motivate much research on nature and health; however, contingency of greenspace-health associations on the character of community change remains understudied.

Methods With aggregate data from governmental sources for 1432 Swedish parishes, we used negative binomial regression to estimate incidence rate ratios (IRRs) for all-cause and cardiovascular disease (CVD) mortality during 2000–2008 in relation to percentage area (in 2000) of urban residential greenspace, urban parks and rural greenspace, looking across parishes with decrease, stability or increase in population density. We also assessed interactions between land use and population change.

Results Parishes with ≥1 decile increase in population density had lower incidence of all-cause (IRR=0.91, 95% CI 0.87 to 0.95) and CVD mortality (IRR=0.89, 95% CI 0.84 to 0.94) compared with parishes with stable populations. In stable parishes, all-cause mortality was lower with higher percentages of urban green (IRR=0.998, 95% CI 0.996 to 1.000) and rural green land uses (IRR=0.997, 95% CI 0.996 to 0.999). These results were inverted in densifying parishes; higher all-cause mortality attended higher initial percentages of urban (IRR=1.081, 95% CI 1.037 to 1.127) and rural greenspace (IRR=1.042, 95% CI 1.007 to 1.079) as measured in 2000. Similar associations held for CVD mortality.

Conclusions More greenspace was associated with lower all-cause and CVD mortality in communities with relatively stable populations. In densifying communities, population growth per se may reduce mortality, but it may also entail harm through reductions in amount per capita and/or quality of greenspace.special-featureunlocked

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To cite: Hartig T, Astell-Burt T, Bergsten Z, *et al. J Epidemiol Community Health* 2020;**74**:534–540.

INTRODUCTION

Urbanisation and urban densification provoke concern about the loss of greenspace.[1 2] Provisions for housing, transportation, workplaces and services diminish greenspaces in and around cities. This degrades biodiversity, ecosystems and living conditions. Alarmed by such problems, many actors now work to equitably integrate green infrastructure in an urban fabric, thus conserving ecological values and ensuring opportunities for all to experience nature.[3–6]

These measures draw support from research on greenspace as a health resource. Reviews of observational and experimental studies affirm that greenspaces can serve mental and physical health in many ways, for example, by reducing exposures to noise, heat and air pollution and by supporting physical activity, social interaction and psychological restoration.[7–9]

This affirmation of greenspace values is, however, qualified; findings for specific pathways and outcomes show considerable heterogeneity. Benefits may vary with age, gender and socioeconomic status.[10–12] They may also depend on contextual features such as degree of urbanicity.[13 14] Further, greenspace measures may have different implications for health at different levels of analysis. For example, more greenspace near a residence may signify more opportunities for physical activity, but more greenspace in the city as a whole may imply a harmful population dependency on automobiles.[15] Thus, contingency of benefits can stem from variation across individuals and communities in the potency of different mechanisms and the aspects of greenspace they engage.

A likely contextual influence suitably studied across communities involves the trajectory of population change. The narrative motivating research on greenspace and health emphasises loss of greenspace with urban expansion and densification. Yet, some communities have shrinking populations,[16 17] which may have other implications for causal mechanisms. For example, loss of greenspace as a setting for stress recovery may have particular salience in growing cities where many people have hectic working lives. In contrast, deterioration of the built environment and loss of services may have more salience in shrinking communities, where an unplanned and unwanted return of green 'wilderness' may reflect loss of control and dim future prospects.[18]

Here, we examine this neglected form of potential contextual influence on the consistency of association between greenspace and health. We do so looking across trajectories of population change in Swedish parishes during 2000–2008. An historical account of parish origins,[19] studies of contemporary local identities and civil initiatives among their populations[20] and current Swedish debates on the importance of traditional parishes[21] indicate that this territorial subdivision remains relevant in people's lives, whether as isolated rural settlements or areas within cities. The period under study saw Sweden's population grow from ca. 8.86 million to ca. 9.26 million.[22] Growth was, however, unevenly distributed; the largest cities saw continuous growth,[16] while some smaller communities shrank. Starting from the size of the parish population in

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2000 and the distribution of different land uses at that time, we consider implications of subsequent population change for the association between greenspace and both all-cause and cardiovascular disease (CVD) mortality. Lower CVD mortality with more urban greenspace is a relatively reliable finding,[23] plausible in light of commonly cited pathways (stressor mitigation, psychological restoration, physical activity, social interaction; 7–9).

We address the following question: To what extent does the direction of population change moderate associations between greenspace and mortality? To arrive at an answer, we consider the initial population density of the parish and its land uses and sociodemographic changes attendant on population change. We focus on parishes with stable boundaries for the period, for which substantial change in population would likely be accommodated by change in land uses. Our analyses include urban and rural greenspace indicators that refer to land uses with potentially different implications for health.[13]

METHODS

Data sources

The Swedish National Board of Health and Welfare (*Socialstyrelsen*) provided the annual mortality data for the period, aggregated by parish. We obtained the land use data from the Swedish Mapping, Cadastral and Land Registration Authority (*Lantmäteriet*), which used CORINE satellite images from 2000 to create a digital map with land use categories suited to Swedish conditions. We extracted sociodemographic data from a database constructed from registers maintained by Statistics Sweden for production of official statistics. The GeoSweden database includes annual data for all individuals living in Sweden and registered in the social insurance system. It also has geographical coordinates for the 100 m squares in which residences are located. We used these coordinates to select parishes with stable boundaries during 2000–2008 and to determine the area of each parish in different land uses.

Mortality data

The parish-level all-cause and CVD mortality data were provided as counts per annum for men and women separately for each of three age bands (18–49, 50–64 and 65+ years). We defined CVD mortality as codes 390–459 from the 9th revision of the International Classification of Disease (ICD-9) and codes I00-I99 from ICD-10[24] (cf. 12). The unequal age bands reflect facts of CVD incidence: relatively low before age 50, but increasingly important as a cause of death in later years.[25]

Land use data

The land use data for 2000 come with a resolution of 25 m^2. Each 25 m^2 unit has a land use (or land cover) assignment based on its location on the land use map. To couple land use data with each of the parishes with stable geographical boundaries in 2000–2008 (n=1432), we assigned each 25 m^2 unit a parish identification using a centroid in polygon method. The sociodemographic data include information on parish localisation.

We created four land-use indicators based on one or more of the categories in Lantmäteriet's typology[26] and rendered as a percentage of the total parish land area. Dense urban structure comprises centrally located blocks of housing and/or commercial buildings with >80% of the area covered by artificially hardened surface, as well as industrial areas and transport infrastructure. Less dense urban structure with greenspace (hereinafter 'green urban') comprises areas with 30%–80% coverage by buildings and other hardened surfaces and the remainder in gardens and greenspace. The urban park indicator comprises areas with 70% or more of the area covered by vegetation, and the remainder covered by buildings and other artificially hardened surface. The fourth indicator (hereinafter 'rural green') comprises various land uses of a predominantly 'green' character with low levels of habitation and development characteristic of outlying village areas, including agricultural land, forests and facilities with large green areas, such as golf courses. Land uses not comprised by these four indicators for the most part involved forms of open water (eg, waterways, lakes, sea). We did not include such bluespace in analyses because in general it has not been built on to any great extent to accommodate population increase. Our calculation of percentage parish area in each of the four land use indicators was done on the basis of land alone, excluding bluespace. See the online supplemental material for further details on creation of the indicators.

Sociodemographic data

For each parish and each year of our study period, we extracted from the database the total number of residents and the number of people in each gender-by-age-band category (six in total) for which we had mortality data. We also calculated for each parish and year the aggregate values (across age bands) for mean individual disposable income (including social welfare transfers), percentage with university education, and percentage born outside Sweden. Each of these variables could relate to all-cause and CVD mortality and also have opposed trajectories of change in communities with growing versus declining populations.

Classification of parishes by changes in population density

Population density for each parish was calculated based on the number of residents per square kilometre parish land area (excluding bluespace) in 2000 and 2008. Deciles were calculated based on the combined 2000–2008 population density distribution. Stability or change in population density deciles between 2000 and 2008 was then used to classify each parish as (i) 'stable' (not more than one decile increase or decrease in population density; n=1313); (ii) 'densifying' (≥1 decile increase; n=83) or (iii) 'shrinking' (≥1 decile decrease; n=36). Parishes that saw population density changes were spread across the country, but with greater numbers in the southern reaches (see the map in the online supplemental material). Parishes excluded because of unstable borders (n=424) were also spread across the country, though with greater total area in the rural north.

Statistical analysis

Descriptive statistics were calculated for the people and parishes covered by our sample to examine the distributions of the four land-use indicators and covariates across the stable, densifying and shrinking parishes. Associations with all-cause and CVD-specific mortality counts were investigated using negative binomial regressions offset by the natural logarithm of each age-gender-year specific parish population. Initial models included each of the three greenspace indicators (thus excluding dense urban land use), together with adjustment for age group, gender and year as dummy variables. These models were further adjusted for parish population density (continuous) and categories of parish-level population density stability/change, followed by adjustment of all models for potential confounders (mean disposable income, percentages with higher education and foreign born). Potential differential associations between mortality and greenspace indicators across stability/change in population density was investigated by fitting two-way interaction terms between each greenspace indicator and the classification of population density stability versus change. The interaction results were interrogated with models stratified by the population density and change categories. These models were then repeated for males and females separately. Parameters were expressed as incidence rate ratios (IRR). Percentage area in dense urban structure was not included in analyses because its value for each parish is the difference between 100% and the linear combination of the three greenspace indicators. We used the conventional p=0.05 criterion for statistical significance.

RESULTS

Table 1 presents baseline descriptive characteristics of the people studied. Just under 5.5 million people lived in the study parishes in 2000, which saw 68 645 deaths from all causes and 33 646 deaths from CVD specifically (12.5 and 6.1 per 1000 people, respectively). Deaths from all causes and CVD per 1000 people were slightly higher among women than men in 2000 and rose logarithmically with age. They were slightly lower in more affluent parishes, parishes with more foreign-born persons, and those with higher population densities. All cause and CVD mortality per 1000 people were higher both in parishes with very little (<1%) and those with relatively much (≥20%) area in dense urban, green urban and urban park land uses.

Table 2 presents characteristics of the parishes in 2000. Those with stable population densities through to 2008 had much higher population densities on average and higher mean percentages of area in dense urban structure, green urban structure, and urban parks than parishes with >1 decile density increase or decrease over the period. Parishes with increased population densities tended to have higher incomes and slightly higher percentages of university educated. Parishes with decreased population density had the smallest percentages of area in the urban land uses and the highest percentage area in rural green. They also had the lowest means for disposable income, percentage university educated, percentage foreign born and population density.

Table 3 reports results of the negative binomial regressions, absent the tests of interaction between the community change and land use indicators. After adjustment for all covariates, parishes with ≥1 decile increase in population density between 2000 and 2008 had lower incidence rates for all-cause and CVD mortality compared with parishes with stable population densities. In contrast, parishes with shrinking populations had higher rates compared with the stable parishes; however, the difference was not statistically significant. Parishes with higher percentages of both green urban and rural green land uses in 2000 tended to have lower rates of all-cause and CVD mortality over the subsequent period. Percentage area in urban parks was not significantly related to incidence of all-cause or CVD mortality. Online supplemental tables S1 and S4 present the complete results for these analyses (Model 1 in each table). The magnitude and statistical significance of coefficients remained approximately the same for all-cause mortality with stratification by gender (online supplemental tables S2 and S3). The same holds for CVD mortality, with the exception that its association with green urban percentage was no longer significant among males (online supplemental tables S5 and S6).

Table 4 presents results of the regression analyses with stratification by population density change category. In a context of stable population density, a greater percentage of area in green urban and rural green land uses in 2000 was associated with lower all-cause and CVD mortality between 2000 and 2008. In contrast, in parishes that saw population density increase over the study period, more greenspace of any kind in 2000 was associated with significantly *higher* all-cause and CVD mortality. Among parishes with population density decrease, no association between a greenspace indicator and either all-cause or CVD mortality reached statistical significance.

The formal interaction tests gained power from inclusion of all parishes, and some aspects of the picture did change. For one, in shrinking versus stable parishes, the unfavourable association for percentage area in urban parks (in table 4) became statistically significant (all-cause IRR=1.226, 95% CI 1.042 to 1.442, p=0.014; CVD IRR=1.268, 95% CI 1.038 to 1.549, p=0.020) (online supplemental tables S1 and S4, Model 3).

Another difference involves rural greenspace. In the stratified analyses (table 4), greater percentage rural green area was attended by lower all-cause and CVD mortality in the stable parishes but with higher all-cause and CVD mortality in parishes with increased population densities. In the formal interaction tests, however, the incidence rates for percentage area in rural green are *lower* in parishes with increased population density versus stable parishes, though significantly so only for CVD mortality (IRR=0.995, 95% CI 0.990 to 0.999, p=0.019) (online supplemental tables S1 and S4, Model 4).

These differences may reflect on absence of adjustment for the main effect of density change in the stratified analyses; with inclusion of the interaction term for rural green percentage (Model 4 in online supplemental tables S1 and S4), the IRRs for the density change categories differ from those seen in Models 1–3, with extreme and yet non-significant values for the shrinking parishes. These values likely reflect on the small number of shrinking parishes and the fact that most of them had a large percentage of rural green space. This aside, addition of the interaction terms in general enhanced model fit; see the results of the likelihood ratio tests given in online supplemental tables S1–S6.

The coefficients for the tests discussed above retain approximately the same pattern for all-cause and CVD mortality after stratification by gender (online supplemental tables S2, S3, S5–S7), though differences in magnitude and statistical significance occur, some presumably reflecting the 50% reduction in power. Independent of type of change in population density, higher mean parish population densities are significantly associated with higher incidence of all-cause and CVD mortality (online supplemental tables S1–S6).

DISCUSSION

We considered the extent to which the direction of change in population density moderated associations between different forms of greenspace and mortality across 1432 Swedish parishes over a recent 9-year period. Some of our findings align with concerns behind much of the nature-and-health literature about costs of urbanisation and benefits of preserving and enhancing greenspace. We found that higher mean population density was attended by slightly higher all-cause and CVD mortality. Also, for parishes with relatively stable population densities over the period, each additional percentage area in urban or rural greenspace was associated with 0.1%–0.3% fewer deaths from all causes and CVD. Though such numbers may seem small, in aggregate they hold practical significance, in this case roughly comparable to the protective value of university education for all-cause mortality.

Other findings, however, point to the need for nuance when discussing urban densification and the values of greenspace. In

Table 1 Characteristics of the sample parishes at baseline (year 2000)

	N (%)	N, all deaths	All deaths per 1000	N, CVD deaths	CVD deaths per 1000
Full sample	5 498 405 (100)	68 645	12.5	33 646	6.1
Gender					
Men	2 682 095 (48.8)	32 501	12.1	15 949	5.9
Women	2 816 310 (51.2)	36 144	12.8	17 697	6.3
Age group					
18–49 years	2 978 258 (54.1)	1628	0.5	415	0.1
50–64 years	1 311 626 (23.9)	6211	4.7	1963	1.5
≥65 years	1 208 521 (22.0)	60 806	50.3	31 268	25.9
Mean disposable income*					
Tertile 1: 438.1–1110.6	1 109 737	17 400	15.7	8697	7.8
Tertile 2: 1110.6–1299.9	1 911 830	26 089	13.6	12 934	6.8
Tertile 3: 1300.5–2439.9	2 476 838	25 156	10.2	12 015	4.9
% university education					
Tertile 1: 3.4%–13.2%	733 504	11 961	16.3	6138	8.4
Tertile 2: 13.2%–18.6%	1 319 734	18 363	13.9	9198	7.0
Tertile 3: 18.7%–68.0%	3 445 167	38 321	11.1	18 310	5.3
% born outside Sweden					
Tertile 1: 0%–4.5%	591 979	8684	14.7	4378	7.4
Tertile 2: 4.5%–7.8%	1 124 905	14 918	13.3	7502	6.7
Tertile 3: 7.8%–64.5%	3 781 521	45 043	11.9	21 766	5.8
Population density					
Tertile 1: 0.1–7.4	427 518	7088	16.6	3639	8.5
Tertile 2: 7.4–29.8	798 748	10 670	13.4	5397	6.8
Tertile 3: 30–20 999.4	4 272 139	50 887	11.9	24 610	5.8
% area in dense urban					
<1%	1 621 202	22 401	13.8	11 309	7.0
1%–4%	1 411 952	16 011	11.3	7829	5.5
5%–9%	810 872	9151	11.3	4341	5.4
10%–19%	778 599	9801	12.6	4738	6.1
≥20%	875 780	11 281	12.9	5429	6.2
% area in green urban					
<1%	939 548	13 588	14.5	6890	7.3
1%–4%	1 154 878	14 879	12.9	7407	6.4
5%–9%	728 629	8291	11.4	4082	5.6
10%–19%	956 907	11 103	11.6	5351	5.6
≥20%	1 718 443	20 784	12.1	9916	5.8
% area in urban park					
<1%	1 400 382	19 463	13.9	9816	7.0
1%–4%	1 334 818	16 222	12.2	7983	6.0
5%–9%	1 135 679	13 160	11.6	6374	5.6
10%–19%	939 529	10 881	11.6	5166	5.5
≥20%	687 997	8919	13.0	4307	6.3
% area in rural green					
<1%	639 431	7732	12.1	3671	5.7
1%–4%	206 652	2597	12.6	1195	5.8
5%–9%	54 195	729	13.5	400	7.4
10%–19%	132 146	1611	12.2	758	5.7
≥20%	4 465 981	55 976	12.5	27 622	6.2

*Mean disposable income is given in 100s of Swedish crowns and for individuals rather than households.
CVD, cardiovascular disease.

contrast to the findings for the stable parishes and to an emphasis on urban pathology common in the nature-and-health literature, parishes that experienced ≥1 decile increase in population density also had lower incidence of all-cause and CVD mortality.

For growing parishes, we also saw that a greater percentage of urban greenspace was attended by *higher* incidence of all-cause and CVD mortality compared with the stable parishes, both in the stratified analyses and in the formal interaction tests. However, to

Table 2 Characteristics of the parishes at baseline (year 2000) by community change context

Population density decile 2000–2008 (n)	Stable (70 902)	≥1 decile increase (4482)	≥1 decile decrease (1944)
	Mean (SD) (Min–Max)		
Total area (km^2)	209.27 (730.55) (0.23–13 521.52)	63.39 (67.22) (10.80–369.64)	131.23 (116.47) (9.90–474.08)
Dense urban percentage	3.57 (11.17) (0–98.24)	0.98 (1.87) (0–9.73)	0.15 (0.36) (0–1.98)
Green urban percentage	5.38 (11.51) (0–75.91)	2.52 (5.45) (0–30.34)	0.30 (0.55) (0–2.34)
Urban park percentage	2.78 (6.72) (0–58.39)	1.44 (3.66) (0–17.04)	0.23 (0.37) (0–1.71)
Rural green percentage	88.27 (24.55) (0–100.00)	95.05 (10.38) (52.44–100.00)	99.32 (1.05) (95.08–100.00)
Mean disposable income	1429.40 (319.59) (309.58–3294.68)	1558.37 (330.40) (770.25–3136.18)	1263.41 (253.28) (621.82–2178.83)
Overseas born percentage	8.65 (7.14) (0–71.25)	8.55 (9.34) (0–68.01)	6.99 (4.58) (1.15–30.14)
Higher education percentage	20.08 (9.50) (3.30–72.16)	21.97 (7.12) (8.80–55.72)	14.40 (5.19) (4.10–34.97)
Parish population density mean	386.41 (1662.53) (0.12–22 522.20)	67.40 (151.21) (2.00–689.24)	6.28 (4.21) (2.40–24.19)

Values for n (the number of observations) are the number of parishes × 9 years × six age/gender categories. The values for total area are for land only; they exclude area in bluespace.

understand this association, the increase in population density must be set against the land uses measured in 2000. The parish borders remained the same from 2000 to 2008, so the total amount of greenspace is unlikely to have increased as population increased. Conceivably, the higher incidence rates stem from greater loss of urban greenspace than in already more populous, urbanised parishes with relatively stable population densities. Where densification did not come at the cost of existing urban greenspace, population growth might still have diminished greenspace per capita and its quality. Thus, the inverted associations need not imply that the greenspaces caused harm; they could reflect, for example, on the emergence of a low-density development pattern that entailed increases in use of car transportation.[15]

The findings for the 36 parishes that saw a decrease in population density also point to a need for nuance. When compared with the stable parishes in formal interaction tests, a greater percentage of urban park area was in those parishes attended by significantly higher mortality, both all-cause and CVD. Speculatively, this finding may reflect on changes in the uses and meanings of parks in communities that could no longer maintain or police them.[18]

Longitudinal ecological studies like this one can describe how the health of populations relates to stability and change in local environmental circumstances. Some may fault our study design out of fear of the ecological fallacy, but here we sought to make inferences about communities rather than individuals living in them. The study does, however, have limitations. It was conducted in a wealthy society with generally low urban population densities; results may not readily generalise to other societies. We did not have land use data for years other than 2000. The available data enabled us to study the implications of change in the population subsequent to the year in which land uses were measured, but we would have preferred to consider implications of population and environmental change together. In particular, it would have been helpful to examine the implications of different approaches to accommodating population increase, for example, with automobile-dependent sprawling development versus high density multifamily housing concentrated in central areas. Our greenspace indicators were coarse, but the variation in results we have reported shows that the land-use distinctions they did represent had relevance for our outcomes. The period of study was arguably brief; however, it was sufficiently long for observation

Table 3 Adjusted associations between all-cause and CVD mortality and measures of population density change and greenspace

	All-cause mortality	CVD mortality
	Incident rate ratio (95% CI), p value	
Population density decile 2000–2008		
Stable (reference)		
≥1 decile increase	0.911 (0.871 to 0.953), p<0.001	0.889 (0.839 to 0.941), p<0.001
≥1 decile decrease	1.030 (0.961 to 1.104), p=0.406	1.056 (0.967 to 1.153), p=0.226
Greenspace indicators		
Green urban percentage	0.998 (0.996 to 1.000), p=0.036	0.998 (0.995 to 1.000), p=0.021
Urban park percentage	1.000 (0.997 to 1.002), p=0.872	1.001 (0.998 to 1.004), p=0.631
Rural green percentage	0.997 (0.996 to 0.999), p<0.001	0.998 (0.996 to 0.999), p=0.006

Models adjusted for year, gender, age group, mean disposable income, foreign born percentage, higher education percentage and parish population density mean. Dense urban percentage is not included here because its value for each parish obtains from a linear combination of the remaining three land use indicators.
CVD, cardiovascular disease.

Table 4 Adjusted associations between all-cause and CVD mortality and greenspace indicators, stratified by population density change

	All-cause mortality	CVD mortality
	Incident rate ratio (95% CI), p value	
Green urban × population density 2000–2008		
Stable	0.998 (0.996 to 1.000), p=0.018	0.997 (0.995 to 0.999), p=0.008
≥1 decile increase	1.081 (1.037 to 1.127), p<0.001	1.105 (1.047 to 1.166), p<0.001
≥1 decile decrease	1.105 (0.847 to 1.440), p=0.461	1.317 (0.858 to 2.023), p=0.208
Urban park × population density 2000–2008		
Stable	1.000 (0.997 to 1.002), p=0.851	1.001 (0.998 to 1.004), p=0.651
≥1 decile increase	1.094 (1.021 to 1.172), p=0.011	1.105 (1.005 to 1.213), p=0.038
≥1 decile decrease	1.221 (0.907 to 1.642), p=0.188	1.088 (0.645 to 1.837), p=0.752
Rural green × population density 2000–2008		
Stable	0.997 (0.996 to 0.999), p<0.001	0.998 (0.996 to 0.999), p=0.007
≥1 decile increase	1.042 (1.007 to 1.079), p=0.019	1.054 (1.008 to 1.102), p=0.022
≥1 decile decrease	0.997 (0.861 to 1.154), p=0.965	1.019 (0.801 to 1.297), p=0.876

CVD, cardiovascular disease.

of beneficial change with densification per se and consequences of population change for health in relation to greenspace values. Further research can consider how health and land use changes go together over longer periods.

CONCLUSION

Alarmed by degraded living conditions for humans and non-humans alike, many actors now work to protect and develop green infrastructure and have it equitably integrated in an urban fabric.[3–6] Our findings call attention to values inherent to built urban fabric as well as greenspace. They also offer targets for research on how benefits of population growth in small communities weigh against possible costs from greenspace losses. As it stands, narratives about greenspace as an antidote to urban pathologies must be reconciled with research on how urbanisation benefits health.[27 28]

What is already known on this subject

- ► Health benefits attributed to greenspace vary across persons and contexts, presumably reflecting the contingent action of causal mechanisms.
- ► Urbanicity has received attention as a contextual effect modifier, but change in community population density as a moderator of greenspace benefits remains understudied, despite widespread concerns about negative health impacts of urbanisation.

What this study adds

- ► We offer a novel illustration of how associations between greenspace and health can vary across different contexts of community change.
- ► Parishes that had relatively stable populations from 2000 to 2008 tended to already have larger populations and higher population density at the start of the study period. For these parishes, more urban residential greenspace was associated with lower all-cause and cardiovascular disease (CVD) mortality over the 9 years.
- ► In contrast, in densifying parishes, more residential greenspace at the start of the period was attended by subsequently *higher* incidence rates for all cause and CVD mortality. These parishes had smaller populations to begin with, as well as lower population density and smaller percentages of area in urban land uses. Over the study period, they also saw *reduced* mortality with densification per se. Thus, densification may undermine public health benefits of residential greenspace, perhaps through loss of area and quality; however, it may confer other benefits that offset the loss, at least as seen in some indicators.

Acknowledgements Work on this study was aided by a Vice Chancellor's International Scholar Award to TH from the University of Wollongong, Australia. We thank the anonymous reviewers for their constructive comments.

Contributors TH, TAB and XF led the design of the study, analyses of the data and wrote the initial draft of the manuscript. ZB and JA prepared the land use and sociodemographic data and contributed to the interpretation of findings and redrafting of the manuscript. RM contributed to the study design, interpretation of findings and redrafting of the manuscript. All authors have confirmed the final version of the manuscript.

Funding RM's contribution was supported by the Neighbourhoods and Communities research programme (MC_UU_12017/10) at the MRC/CSO Social & Public Health Sciences Unit.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval The Swedish National Board of Health and Welfare provided the aggregated mortality data after in-house review regarding privacy concerns (Dnr 28216/2012). Use of the aggregated sociodemographic data required no ethical review beyond that already done for creation of the database from which it was extracted.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. The aggregate sociodemographic data are available from Statistics Sweden. The land use data are available from the Swedish Mapping, Cadastral and Land Registration Authority. The aggregate mortality data may be obtained from the Swedish National Board of Health and Welfare, subject to their internal review.

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