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Deprivation Indices, Population Health and Geography: An Evaluation of the Spatial Effectiveness of Indices at Multiple Scales

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ABSTRACT *Area-based deprivation indices (ABDIs) have become a common tool with which to investigate the patterns and magnitude of socioeconomic inequalities in health. ABDIs are also used as a proxy for individual socioeconomic status. Despite their widespread use, comparably less attention has been focused on their geographic variability and practical concerns surrounding the Modifiable Area Unit Problem (MAUP) than on the individual attributes that make up the indices. Although scale is increasingly recognized as an important factor in interpreting mapped results among population health researchers, less attention has been paid specifically to ABDI and scale. In this paper, we highlight the effect of scale on indices by mapping ABDIs at multiple census scales in an urban area. In addition, we compare self-rated health data from the Canadian Community Health Survey with ABDIs at two census scales. The results of our analysis confirm the influence of spatial extent and scale on mapping population health—with potential implications for health policy implementation and resource distribution.*

KEYWORDS *Deprivation indices, MAUP, Population health, Scale.*

A BRIEF BIOGRAPHY OF POPULATION HEALTH INDICES COMMONLY USED IN CANADA

The use of census data to quantify socioeconomic deprivation is a generally well-accepted method of identifying populations with poorer health outcomes.[1–5] The history of census-based area deprivation indices dates back to at least until 1971, when the Department of the Environment (DOE) in the United Kingdom used data taken from the census to identify localities where a high proportion of households were exposed to adverse social and economic conditions.[6] The indices were developed to more effectively identify areas in need of resources to improve quality of life. Publications stemming from *The Black Report*,[7] the *Whitehall*,[8] and *Acheson* studies[9] launched additional public scrutiny of the relationship between socioeconomic gradients and health status. These studies have spurred a relatively new yet increasingly popular framework that uses socioeconomic data taken from the census to quantify deprivation and demonstrate its relationship with population health.[2,10–14]

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In the Canadian context, a number of deprivation indices have been proposed to assess the conditions that give rise to deprivation for populations living in rural and urban areas. Like their UK counterparts,[2,10,14] the indices presented in Frohlich,[11] Pampalon,[13] and Langlois[12] were designed to identify the conditions unique to Canadians living in Manitoba and Montreal. The Socioeconomic Factor Index (SEFI) proposed in Frohlich[11] has been used to draw linkages between incidents of low income and readmission of newborns,[15] and to identify the conditions that affect adolescent reproductive health.[16] Similarly, the General Deprivation Index (GDI) proposed in Langlois[12] and the Deprivation Index for Health and Welfare Planning for Quebec (DIHWPQ) constructed in Pampalon[13] have both been used to further conceptualize the spatial dimensions of inequality for measuring health and well-being and for health care planning.[17,18] Although significant attention has been directed toward how measures of socioeconomic inequality should be constructed, comparably less attention has been spent addressing the influence of scale.

We argue that although deprivation indices are worthwhile indicators of disadvantage when used at medium (Census Tract/Census Ward) to small (Census Dissemination Area/Enumeration Area) spatial scales, it is more difficult to identify exactly which subpopulations are in need when working with medium aggregate population data. In addition, spatial extent or scale at which the indices are calculated has an effect on their values. Despite some attention to the susceptibility of boundary classification on the index results,[19–21] there has been little explicit evidence of this concern within the day-to-day practical use of socioeconomic indicators.[16,22–24] Notable exceptions in the health literature include research conducted by Soobader et al.[25,26] and Krieger et al.[27] The results of both studies demonstrate the added importance of addressing contextual and compositional effects on health and the susceptibility (and variability) of area-based socioeconomic measures to the level of aggregation used to construct the metric. In addition, both Soobader et al.[25] and Krieger et al.[27] stress the tension inherent in socioeconomic inequalities research of the lack of a common geographic standard best suited for health and socioeconomic data analysis. The complexity of scale on research analysis is of critical importance because of the growing number of deprivation indices used in Canada to report on health outcomes for the purposes of resource distribution and policy implementation.[28–30] The regionalization of Canadian health care services into large administrative areas that are managed by the provinces further stresses the added importance of addressing the influence of scale and administrative zoning structure when addressing social gradients in health outcomes.

This paper begins by outlining the context in which deprivation indices are commonly composed and critiqued. Using the Vancouver Census Metropolitan Area (CMA) as a study area, we illustrate how the scale of census boundaries used to map deprivation indices affects the results. This research is especially important for researchers reporting on neighborhood studies of deprivation in rural and urban areas for the purposes of health policy implementation and resource distribution.

THE UBIQUITY OF DEPRIVATION INDICES

Relative deprivation is a comparative measure. Unlike absolute deprivation, which refers to a threshold of minimum necessity, such as a low income cut-off, relative deprivation refers to a state of disadvantage experienced by individuals or communities relative to surrounding population.[21] Population comparisons are made at the same spatial extent. Deprivation is typically divided into two primary constructs that

illustrate disadvantage based on measurements of *social position* and *material access* (see Table 1). Measurements of social position, also referred to as social fragmentation or social deprivation, define collective functions encompassing the social environment, such as levels of community or family support, rights of members within society, or the influence of environmental conditions surrounding labor environments. Direct measurements of social deprivation, however, are exceedingly difficult to obtain given the detailed breadth of collecting administrative data on social integration. Until now, social deprivation has been best measured indirectly using the Registrar General's social class classification system composed within the British Census. This classification is unavailable within Canadian and U.S. censuses. Instead, individual or area social deprivation is implied using a combination of income and education constructs. Measuring material deprivation entails identifying a population's ability to access services or goods, such as educational or employment opportunities, community resources, or the ability to find suitable housing. As such, material deprivation is easier to measure using census data, which routinely includes information on individual income, employment, and housing.

Investigators use measures of material and social deprivation at a variety of spatial scales to postulate the relationship between social and economic inequalities and health inequalities.[32,33] Their objective is to classify high-risk populations, or the areas in which they live, to inform policy makers to supply a combination of social and material resources to enhance their quality of life. They are also a pragmatic measure in that deprivation indices tend to utilize socioeconomic data that are available in multiple jurisdictions, most commonly found in the census. Implicit in the use of such indices in population health is that populations living in areas of higher social status and access to resources are at a lower risk of ill health.[13,34]

Critiques of both the UK and Canadian indices tend to focus either primarily on the subjectivity of the indicator selection or the weighting algorithms associated with their aggregation.[11,35–37] Both UK and Canadian indices are limited as they do not entirely convey information about all factors indicative of deprivation that contribute to quality of life. Auxiliary problems also include lack of or difficulty accessing sufficient individual longitudinal health data, which necessitates relying on area-based statistics to quantify individual health patterns at a larger scale.[11,21] Additional caveats are associated with varied semantic interpretations of the variables. For the most part, however, critiques of deprivation indices fail in explicitly accounting for ways in which the choice and design of the spatial unit (e.g., census tract or census subdivision) shapes the result of the analysis.

An increasing number of population health researchers have adopted techniques frequently employed by geographers in emphasizing the inherent difficulties of interpolating between spatial scales. Notable contributions work on addressing the variability of specific health and socioeconomic outcomes according to spatial extent[27] and assessing levels of uncertainty associated with small-area health data.[38,39] This research continues within this vein and is particularly relevant to deprivation research where choice of scale is a means of identifying populations at a high risk of health inequalities with greater confidence.

THE EFFECT OF MODIFIABLE AREA UNIT PROBLEM (MAUP) ON DEPRIVATION INDICES

Spatial units associated with socioeconomic status (SES) data are typically constituted by administrative fiat. Common Canadian examples include dissemination

TABLE 1 Structure of seven deprivation indices, including: the Jarman UPA 8;[2] the Carstairs Index;[10] the Townsend index;[14] the Socioeconomic Factor index (SEFI);[11] the Deprivation Index for Health and Welfare Planning in Quebec (DIHWPQ);[13] the General Deprivation Index (GDI);[12] and the Vancouver Area Neighborhood Deprivation Index (VANDIX)[31]

Measure	Jarman†	Carstairs†	Townsend†	SEFI*	DIHWPQ*	GDI*	VANDIX*
Type of index							
Material deprivation	X	X	X	X	X	X	X
Social deprivation	X	X		X	X	X	X
Categories of variables used							
Income variables		X		X	X	X	X
Housing variables	X	X	X			X	X
Demographic variables	X			X	X	X	X
Mobility variables	X	X	X				
Education variables				X	X	X	X
Employment variables	X	X	X	X	X	X	X
Social class	X	X					
Variable weighting method							
Principal component analysis				X	X	X	
Log transformations			X				
Expert weighting	X						X
Multiple linear regression				X			
Geographic unit of analysis							
Wards	X	X	X				
Enumeration/dissemination aAreas					X		X
Census tracts						X	X
Municipal boundaries				X			

Key: (†) UK deprivation index; (*) Canadian deprivation index

areas, census tracts, electoral districts, and municipal or other larger health administrative boundaries (see Figure 1). The borders of these units are not designed to reflect zones of homogeneity with respect to population health but criteria such as shape compactness and a threshold number of households. Nevertheless, these units are widely used because socioeconomic census data are aggregated for these spatial units. Unaggregated census data are not publicly available to protect individual household confidentiality.

Geographers are increasingly sensitive to the effect that spatial scale (i.e., units of analysis) has on research results.[40–43] The modifiable area unit problem (MAUP)

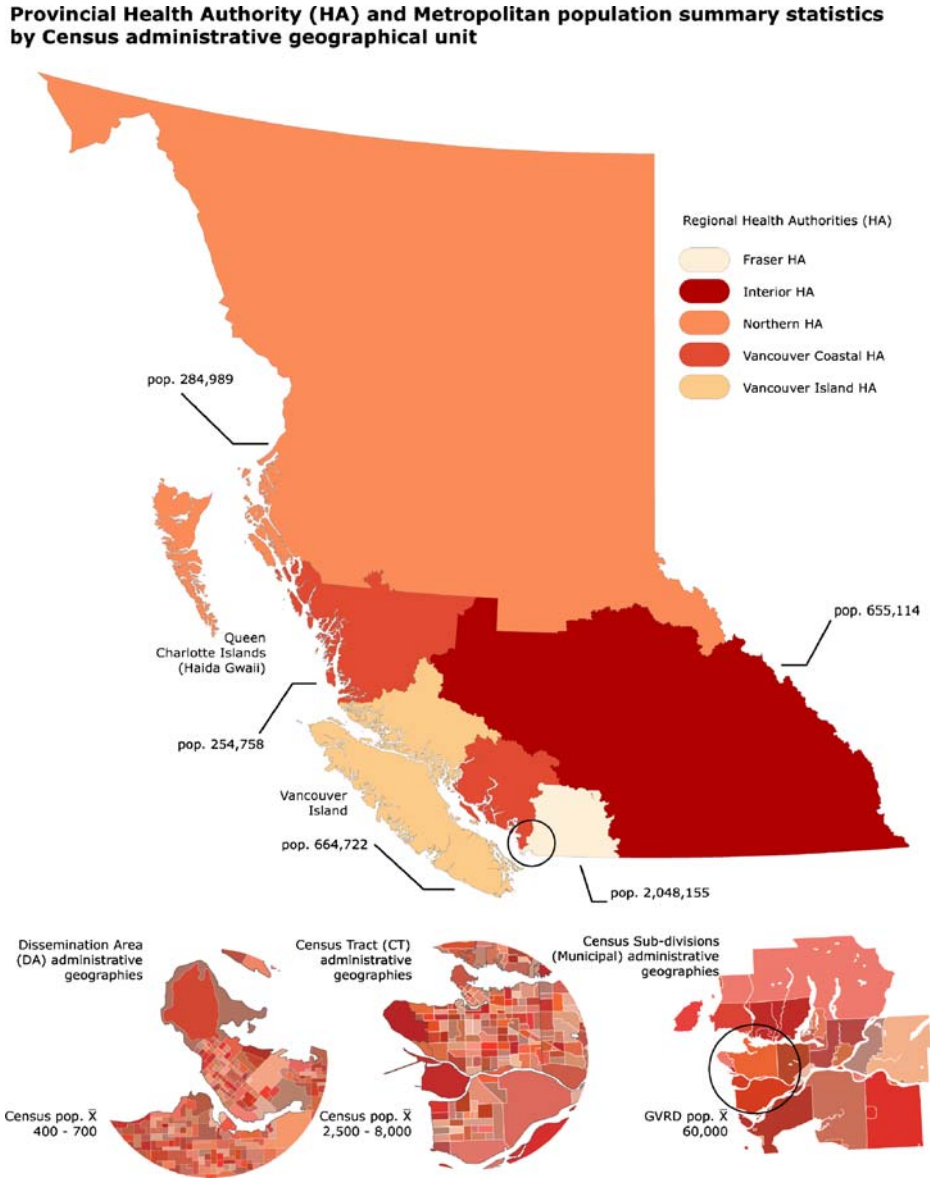

FIGURE 1. Efforts to regionalize health care in Canada have placed service provision primarily on the provinces. Note that as you move down from a provincial level to a neighborhood scale the ability to predict neighborhood instances of lower SES and health outcomes increases.

refers to the problem that occurs when inferences—based on spatial analysis—change when the same data are analyzed using either variations in administrative zoning or through different scales.[44–46] This influences not only subsequent results of analysis made based on such data, but also how these results are interpreted.[47] This effect occurs because census and other data about populations are in aggregate form, and inferences about individuals are made using such aggregate data.[45,48]

The first component of the MAUP, the scale effect, is the tendency, within a system of modifiable areal units, for different statistical results to be obtained from the same set of data when the information is grouped at different levels of spatial resolution (e.g., census blocks, tracts, districts, counties, and regions).[46] The second component of the MAUP is illustrated by a frustration commonly experienced by researchers investigating relationships between place and health. They are often constrained by the geographic boundaries employed by producers of the secondary data they are using. The zoning effect is the variability in statistical results obtained within a set of modifiable areal units as a function of the various ways that these units can be grouped *at a given scale*, and *not* as a result of the variation in the size of those areas, i.e., the difference in results, which follows from merely altering the boundaries or configurations of the zones at a given scale of analysis.[46] A full appreciation of the zoning effect leads to the conclusion that the results of studies of relationships between health and place will *always* be influenced by the zoning strategy used, although as we will demonstrate, scale effects are the more worrisome component of the MAUP when using deprivation indices.

A DEMONSTRATION OF THE SCALE EFFECT ON DEPRIVATION INDICES

Figures 2a and 2b illustrate the scale effect of MAUP using the *Vancouver Area Neighborhood Deprivation Index* (VANDIX) and the *Socioeconomic Factor Index* (SEFI) at three spatial extents: Dissemination Area, Census Tract, and Census Subdivision administrative boundaries within Metropolitan Vancouver. In the 2001 Canadian Census, Dissemination areas (DA) replaced the Enumeration Unit as the basic unit of geographic dissemination. DAs are similar in scope to a single neighborhood block. Census Tracts (CT) are the second smallest geographical unit in the census and are only created for urban areas with a core population over 50,000 people. They represent small and relatively stable geographic boundaries, ranging in population from 2,500 to 8,000 residents per CT. CTs tend to be geographically stable from census to census, but their sociodemographic mix can vary widely. Census Subdivisions (CSD) contain a large number of DA and CT administration units. They are equivalent to a city municipality.

Figures 2a and 2b show both indices against Vancouver (city of) using both DA and CT boundaries. The generated scores are also distinguished by the surrounding CSD boundaries for the Metropolitan area. The smaller scale map on the right shows a generalized picture of socioeconomic position, whereas the map on the left shows there is more detailed characterization of small areas. Whereas, in some instances, it may be preferable to work from a lower resolution model, we argue that higher resolution data (e.g., smaller, more numerous spatial units) can assist in identifying specific populations within urban areas that require health services and resource allocations.[49–51] Whereas variable selection is a considerable controlling factor in magnifying or attenuating socioeconomic deprivation,[23] the strength of the indicators are also influenced by the scale in which they are constructed. Table 2

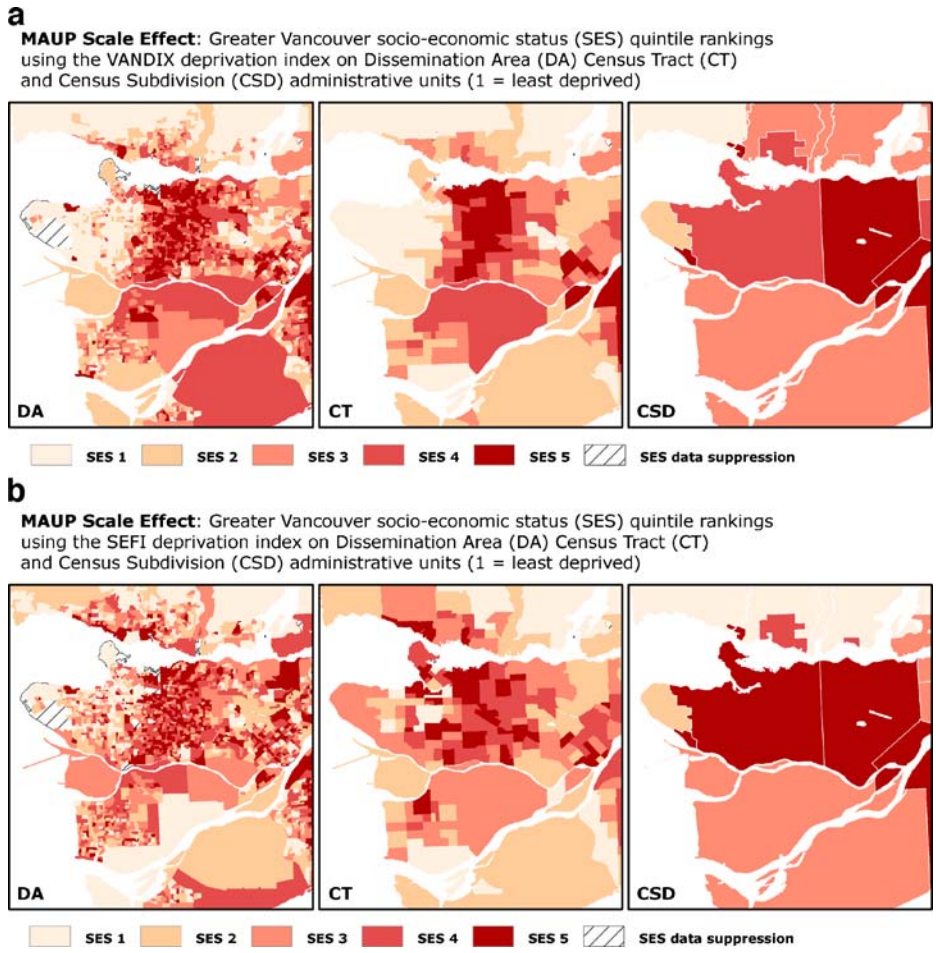

FIGURE 2. (a) MAUP scale effect: Greater Vancouver socioeconomic status (SES) quintile rankings using the VANDIX deprivation index on Dissemination Area (DA), Census Tract (CT), and Census Subdivision (CSD) administrative units (1 = least deprived); (b) MAUP scale effect: Greater Vancouver socioeconomic status (SES) quintile rankings using the VANDIX deprivation index on Dissemination Area (DA), Census Tract (CT), and Census Subdivision (CSD) administrative units (1 = least deprived).

illustrates that there is a statistically significant difference between populations in SES 1 and 2 between DAs and CTs. Clearly aggregation has a homogenizing effect.

A DEMONSTRATION OF THE ZONING EFFECT ON DEPRIVATION INDICES

The zoning effect of MAUP is demonstrated by reconstructing the Census Tract (CT) administrative boundaries (Figures 3a and 3b). Census Tract SES levels are determined through the mean value of the encompassing DAs. CT administrative units contain, on average, 12 DA units. The average CT population for Metropolitan Vancouver is 5,100 residents, whereas DAs contain 500–700 people. These averages vary among DAs and CTs. Both the original CT administrative boundaries and the newly created CT units are contrasted using individual health data for residents living within the Vancouver CMA.

TABLE 2 Variation in socioeconomic quintile ranking for census DA and CT administrative boundaries in the Vancouver CMA

	Dissemination area		Census tracts		
Socioeconomic quintile	Population	Standard error	Population	Standard error	Population difference
SEFI index					
Least deprived (1)	379,111	11.06	379,670	214.25	559*
2	398,072	12.44	382,700	237.87	15,372*
3	403,541	10.37	413,620	213.93	10,079*
4	396,656	9.70	433,400	175.49	36,744*
Most deprived (5)	382,446	7.69	377,405	187.85	5,041*
VANDIX index					
Least deprived (1)	383,935	12.64	381,421	199.69	2,514*
2	410,455	11.60	404,591	222.85	5864*
3	395,190	9.64	403,587	233.64	8397*
4	399,788	9.24	399,860	207.40	72
Most deprived (5)	382,793	7.68	397,351	178.66	14,558*

*Difference between aggregation unit and SES quintile ranking is statistically significant (CI 95%).

Each DA is spatially linked to a CT through a *unique identifier*. A new CT boundary is created by reassigning the DAs unique identifier to a new spatial clustering. The new CT boundaries are based on a contiguous grouping of DAs. The average CT population within the Census Subdivision (municipality) is used to reconstruct the new CT boundaries. Figures 3a and 3b illustrate SES levels for the reconstructed and official CT administrative boundaries.

Individual health data are from the Statistics Canada Canadian Community Health Survey 2.1, a cross-sectional survey designed to provide estimates of health status at the health region level. The target population of the CCHS is persons 12 years or older who are living in private dwellings in the 10 provinces and the three territories. The primary sampling frame used to select households is from the Canadian Labour Force Survey, which uses a multistage stratified design. However, random digit dialing and telephone list frames were used to select households in some health regions.

Data were collected in person and by telephone using Computer-assisted Interviewing (CAI) methods between January and December 2003 for 135,000 respondents with a person-level response rate of 92.6%. In this study we use data for 4,920 17 - to 74-year-olds from a subsample of 6,157 respondents in the Vancouver CMA. Sampling weights were applied to all analysis following Statistics Canada guidelines. To account for the complex sampling design of the CCHS 2.1 coefficients of variance and confidence intervals were calculated using 500 bootstrap weights provided by Statistics Canada using SAS software. Detailed information about the survey methodology, design, and weighting is available elsewhere.[52]

Health status is assessed using "self-rated health," which has been demonstrated to be a reliable indicator of health status and predictive of mortality and adverse health outcomes.[53,54] Self-rated health was assessed by the item GEN_Q01, which asks respondents: "In general, would you say your health is....Fair, Poor, Good, Very Good, Excellent." Responses were dichotomized into "fair or poor" and "good, very good, and excellent" for analysis. Individual postal codes contained in the microdata

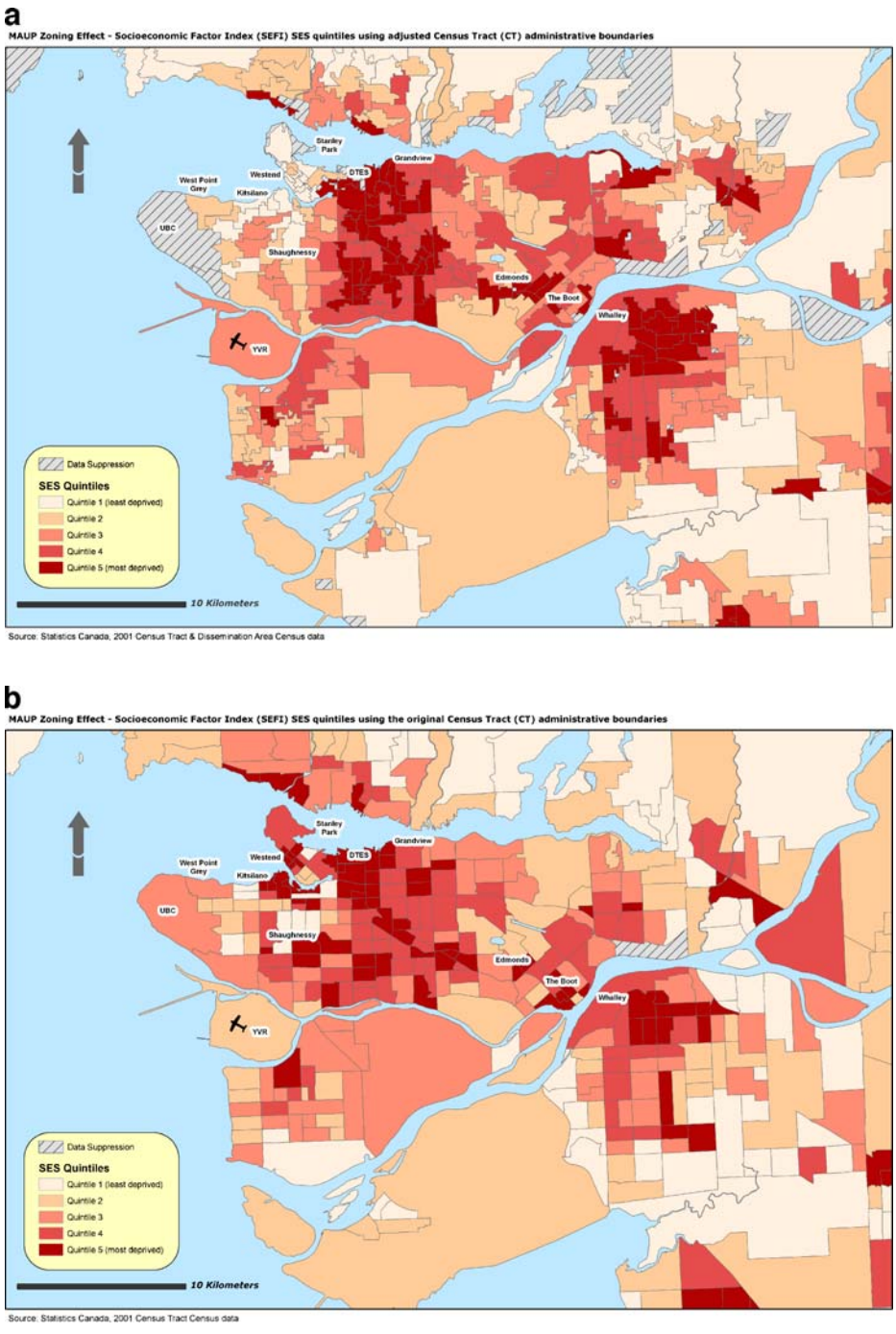

FIGURE 3. (**a**) Zoning Effect of MAUP using the SEFI index for the Vancouver CMA at the Census Tract (CT) extent; (**b**) The original Census Tract (CT) extent of SES distributions using the Socioeconomic Factor Index (SEFI).

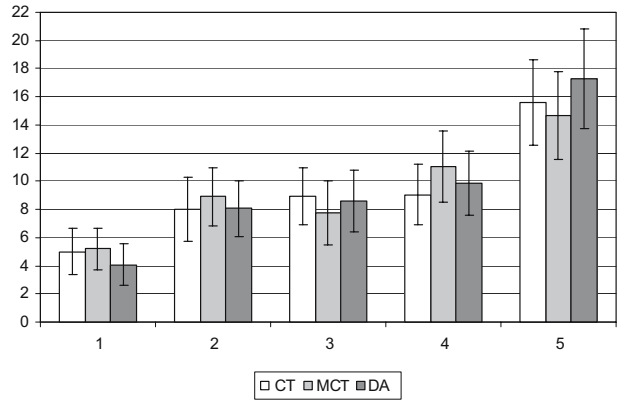

FIGURE 4. Percent "Fair or Poor" Self-rated health by quintiles of VANDIX index for Dissemination Area (DA), Census Tracts (CT), and rezoned Census Tracts (MCT). 1 = least deprived SES quintile; 5 = most deprived SES quintile.

file were used to assign respondents to the Dissemination Area, Census Tract (CT), or Modified CT (MCT) of residence using the Statistics Postal Code Conversion File.

MODIFIABLE AREA UNIT PROBLEM (MAUP) ZONING AND SCALE EFFECT RESULTS

In the Vancouver CMA, the prevalence of reporting "fair or poor" self-rated health was 9.25%. We report the prevalence of "fair or poor" self-rated health by quintiles of the VANDIX index for the three spatial configurations. The CTs and MCT are the same spatial scale, and differences between them represent the zoning effect of the MAUP, whereas differences between the DAs and CT/MCT represent the scale effect. Figure 4 shows the percent of respondents reporting "fair or poor" self-rated health increases with increasing deprivation across all three spatial configurations. The first two bars of each quintile show the percent reporting "fair or poor" self-rated health for the CTs and MCTs. The gradient is marginally stronger for the CTs as estimates of "fair or poor" self-rated health ranges from 4.98% (quintile 1) to 15.62% (quintile 5), whereas the MCT's range is from 5.21% (quintile 1) to 14.67% (quintile 5). As CTs are created to be socially homogenous units, it is likely that this construction results in a slightly stronger gradient compared to the MCTs. Compared to the CTs and MCTs, the gradient of "fair or poor" self-rated health is somewhat stronger for the DA configuration ranging from 4.08% (quintile 1) to 17.3% (quintile 5). Because DAs are smaller spatial units, they are able to capture small areas of deprivation and affluence, which likely results in a slightly stronger gradient (Table 2).

CONCLUSION: SCALE MATTERS

Based on these examples and their analysis, we urge researchers describing population health through the use of indices to remain alert to the effects of scale in describing extent of deprivation. More specifically, we argue that deprivation indices are susceptible to spatial granularity and that the MAUP effect is best ameliorated by using large scales (e.g., the smallest unit of analysis possible) with

higher resolution. Contextual data on health, at any scale, is an asset to health researchers in the absence of more accurate information,[55] but it is evident from the examples of two Vancouver deprivation indices (Figures 3a and 3b) that data resolution has a demonstrable effect on the association between relative deprivation and self-reported health. The influence of MAUP, whereas recognized by population health researchers, continues to have policy significance when assessing relative social and material deprivation in urban populations.

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