Skewed Riskscapes and Gentrified Inequities: Environmental Exposure Disparities in Seattle, Washington

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Objectives. Few studies have considered the sociohistorical intersection of environmental injustice and gentrification; a gap addressed by this case study of Seattle, Washington. This study explored the advantages of integrating air toxic risk screening with gentrification research to enhance proximity and health equity analysis methodologies. It was hypothesized that Seattle's industrial air toxic exposure risk was unevenly dispersed, that gentrification stratified the city's neighborhoods, and that the inequities of both converged.

Methods. Spatial characterizations of air toxic pollution risk exposures from 1990 to 2007 were combined with longitudinal cluster analysis of census block groups in Seattle, Washington, from 1990 to 2000.

Results. A cluster of air toxic exposure inequality and socioeconomic inequity converged in 1 area of south central Seattle. Minority and working class residents were more concentrated in the same neighborhoods near Seattle's worst industrial pollution risks.

Conclusions. Not all pollution was distributed equally in a dynamic urban landscape. Using techniques to examine skewed riskscapes and socioeconomic urban geographies provided a foundation for future research on the connections among environmental health hazard sources, socially vulnerable neighborhoods, and health inequity. (*Am J Public Health.* 2011;101:S246–S254. doi:10.2105/AJPH.2011.300174)

Analysis of environmental injustice proliferated across the social sciences in recent decades, with many concluding that injustice and racism were major features of America's urban geographies. Numerous studies found spatial distributions of environmental hazards and socially vulnerable populations (including the poor and minorities) clustered together in metropolitan areas.[1–8] National, state, and local responses to these conditions sought to achieve environmental justice, or

> the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.[9(pvii)]

However, effective efforts were impeded by several critical gaps in data and research on proximity to high risk facilities, the structure of socioeconomic inequity, and their spatial convergence in urban geographies.

Many social and health science publications engaged in the debate on whether the spatial proximity of environmental hazards and socially vulnerable neighborhoods demonstrated intentional patterns of environmental injustice.[10–14] Much of this research relied on narrowly constructed empirical models of the average geographies where pollution and minorities coincided. Far fewer studies considered the historical production of environmental inequities. Because not all pollution was created, nor populations exposed equally, models of the average proximity between pollution and socially vulnerable populations informed public health and environmental agencies little about relative risk, where the worst pollution exposure inequity was and is, and how it impacted health in nearby communities.[15]

Environmental and health inequity analysis was also inhibited by an inadequate accounting of the emergence and growth of socially stratified communities. Numerous scholars examined the historical composition of neighborhoods when hazardous facilities first arrived.[16–24] By questioning intentional discrimination, most found that industrial districts were historically mixed and became majority–minority over time. They also focused on associations between the proximity of hazardous facilities to poor and minority neighborhoods.

This study's empirical combination answered Metzler's[25] call for developing the following to analyze health disparity: (1) researchers operationalized a modifiable determinant of health, (2) analysis included a way of categorizing people into social strata, and (3) researchers compared health determinants across social strata. The methods in this study attempted to provide techniques to meet all 3 while also putting environmental exposure inequality and social stratification in a historical context.

Numerous public health scholars also called for more attention to the underlying social or area level factors and their role in producing inequities.[26–28] Therefore, the first part of this analysis focused on the spatial distribution of the highest hazard toxic air pollution producers in Seattle and their shifting proximity to socially vulnerable neighborhoods from 1990 to 2007. Proximity to these was commonly characterized as an important determinant of health hazard inequity.[29,30] This study joined a small number of studies that enhanced the proximity approach by using relative risk characterizations to better illuminate where the most unequal pollution exposures occurred across urban landscapes.[31–34]

In the second part of the analysis, longitudinal census data was used to analyze the distribution of inequitable development among Seattle's socioeconomic strata. Inequitable development consisted of the emergence and growth of economically and socially divided communities with transition costs falling unfairly on lower income and non-White residents.[35] The research contributed to a growing body of case studies examining the formation of environmental inequality.[36–39] Moreover, as Corburn[40] observed, too little research examined the overlap of the fields of urban planning and public health, and our methodological combination offered a bridging analytic strategy.

The extensive literature on urban environmental injustices was corroborated, and this study offered an empirical application of the varied theoretical development around environmental and health inequity as a sociohistorical process.

METHODS

Relative risk exposure data for this study was taken from the US Environmental Protection Agency's (EPA) Risk Screening Environmental Indicators (RSEI) software (version 2.3) from the Office of Pollution Prevention and Toxics (OPPT). Using only air toxic releases, RSEI was used to derive a relative risk characterization of 90 toxic release inventory (TRI) facilities operating in Seattle from 1990 to 2007.[41] These data were used to test the hypothesis that Seattle's industrial sources of air toxic exposure risk were unequal and unevenly dispersed across the city.

Demographic information on Seattle's census block groups included common measures used by urban geographers to characterize gentrification. Although it has many definitions,[42–47] gentrification generally refers to the upward socioeconomic transformation of urban neighborhoods by income, housing values, education, and occupational levels. Gentrification became a fundamental process and widespread pattern of urbanization after the recession in the 1990s.[48,49] Moreover, the downward shift of these same measures also became another operationalization of social vulnerability.[50–52] Unfortunately, most research analyzed national and regional resolutions that were too coarse to contribute to localized environmental policy or public health practice.[53,54] Instead, this study focused on the city of Seattle and trends in a subset of socioeconomic measures.

Census data were obtained from GeoLytics, a firm that partnered with the Urban Institute and the Rockefeller Foundation to produce the Neighborhood Change Database. It contained census data from 1990 remapped along 2000 spatial boundaries, allowing for the geographic comparison of urban demographic shifts.[55] Census block group data was extracted to compare the longitudinal shifts in Seattle neighborhoods. Built from census blocks, census block groups are the second finest spatial unit available from the US Census and typically contain 600 to

TABLE 1—Seattle's 10 Highest Toxic Release Inventory Air Pollution Exposure Risk Characterizations in 1990, 2000, 2007 and 1990 to 2007

Facility Name	Cluster	Pounds	Risk Value $	Total Risk, %	Cumulative Risk, %
1990					
PSF Industries Inc.	13	7205	14 958 861.86	49.12	49.12
American Tar Co.	5	1255	11 670 515.74	38.33	87.45
Boeing Commercial Airplane Plant 2	15	1 070 553	1 739 932.70	5.71	93.16
Seattle Steel Inc.	2	44 100	1 395 724.49	4.58	97.75
Precision Engineering Inc.	15	250	211 857.68	0.70	98.44
Western Steel Casting Co.	13	1500	171 021.64	0.56	99.00
North Star Casteel Products Inc.	13	1000	67 406.67	0.22	99.23
Northwest Plating Co.	13	37 970	48 096.28	0.16	99.38
Asko Processing Inc.	5	18 134	36 669.09	0.12	99.50
Industrial Plating Corp.	13	27 541	35 994.15	0.12	99.62
Top 10 facility totals	–	1 209 508	30 336 080.32	99.62	99.62
All facility totals (n = 58)	–	2 478 741	30 451 134.28	100.00	100.00
2000					
Sound Propeller Services Lake Union	5	500	640 879.57	74.84	74.84
Alaskan Copper Works	13	30	86 877.07	10.14	84.98
Wescor Graphics Corp.	9	18 240	63 903.48	7.46	92.45
Asko Processing Inc.	5	9925	24 117.29	2.82	95.26
Art Brass Plating Inc.	15	17 820	22 120.05	2.58	97.84
Nucor Steel Seattle Inc.	2	45 223	7457.97	0.87	98.72
Equilon Enterprises LLC	16	3003	2981.70	0.35	99.06
Trim Systems	15	7951	2322.51	0.27	99.33
BP West Coast Products	16	4110	1447.96	0.17	99.50
Viox Corp.	15	238	791.27	0.09	99.60
Top 10 facility totals	–	107 040	852 898.87	99.60	99.60
All facility totals (n = 28)	–	285 736	856 357.67	100.00	100.00
2007					
Sound Propeller Services South Park	15	1000	1 416 190.68	95.07	95.07
Ash Grove Cement Co.	13	224	66 214.38	4.45	99.52
Equilon Enterprises LLC	16	3755	3197.78	0.21	99.73
BP West Coast Products	16	3506	1275.13	0.09	99.82
Saint-Gobain Containers Inc.	15	411	858.71	0.06	99.87
Nucor Steel Seattle Inc.	2	1908	667.14	0.04	99.92
Rudd Co. Inc.	2	9824	362.88	0.02	99.94
Boeing Commercial Airplane Boeing Field	15	3490	329.36	0.02	99.96
Ballard Brass & Aluminum	2	250	119.64	0.01	99.97
Lafarge North America	15	85	112.33	0.01	99.98
Top Ten Facility Totals	–	24 453	1 489 328.02	99.98	99.98
All Facility Totals (n = 22)	–	38 039	1 489 595.94	100.00	100.00
1990–2007					
PSF Industries Inc.	13	15 864	35 725 552.16	51.15	51.15
American Tar Co.	5	1255	11 670 515.74	16.71	67.86
Alaskan Copper Works	13	1570	6 521 082.06	9.34	77.20
Sound Propeller Services Lake Union	5	5792	4 951 338.11	7.09	84.29
Boeing Commercial Airplane Plant 2	15	2 160 764	2 966 704.02	4.25	88.54
Sound Propeller Services South Park	15	1255	2 191 256.74	3.14	91.68

Continued

TABLE 1—*Continued*

Seattle Steel Inc.	2	44 100	1 395 724.49	2.00	93.68
Western Steel Casting Co.	13	17 170	1 062 167.62	1.52	95.20
Wescor Graphics Corp.	9	175 830	624 489.76	0.89	96.09
Asko Processing Inc.	5	212 094	508 356.23	0.73	96.82
Top 10 facility totals	–	2 635 694	67 617 186.94	96.82	96.82
All facility totals(n = 90)	–	8 793 903	69 838 908.46	100.00	100.00

Source: US Environmental Protection Agency Risk Screening Environmental Indicators (RSEI) Version 2.3.41.

3000 people.[56] The Seattle dataset included 568 census block groups obtained from the compact disc titled *CensusCD 1990 Long Form in 2000 Boundaries*[57] and US Census 2000.[58] In the tradition of neostructural urban geography[59] and following the work of Morrill[60] with Seattle's census tracts, a finer resolution of data and the multivariate statistical methods of classic factorial social ecology[61–65] were used to test the hypothesis that gentrification processes were widespread in Seattle and resulted in a shrinking landscape of affordable housing. It was also expected that Seattle's more socially vulnerable neighborhoods bore more of the burden of proximity to the city's riskiest industrial facilities.

Factorial social ecology is the geographic application of factor analysis to reduce a larger set of social, economic, and demographic measures into smaller groups of variables that describe salient characteristics of a city's census block groups. We compiled and factor analyzed 12 socioeconomic variables for each of the 568 census block groups in Seattle for the 1990 and 2000 census periods. Factor analysis in the form of principal components analysis (PCA) is an effective data reduction technique well suited for the exploratory purpose of the Seattle study.[66–68]

Cluster analysis was then used to group together block groups that shared similar component scores from each PCA analysis.[69,70] This method differentiated areas that experienced gentrification from those that did not and identified where significant changes in socioeconomic character occurred. The most appropriate clustering method for this project was a minimum distance hierarchical technique, called Ward's method, which maximized between-group differences while minimizing within-group differences.[70] This method resulted in small sized clusters (as few block groups as possible) with substantial homogeneity. Thus, block groups that experienced significant change due to gentrification were well-differentiated from those that experienced other trajectories.

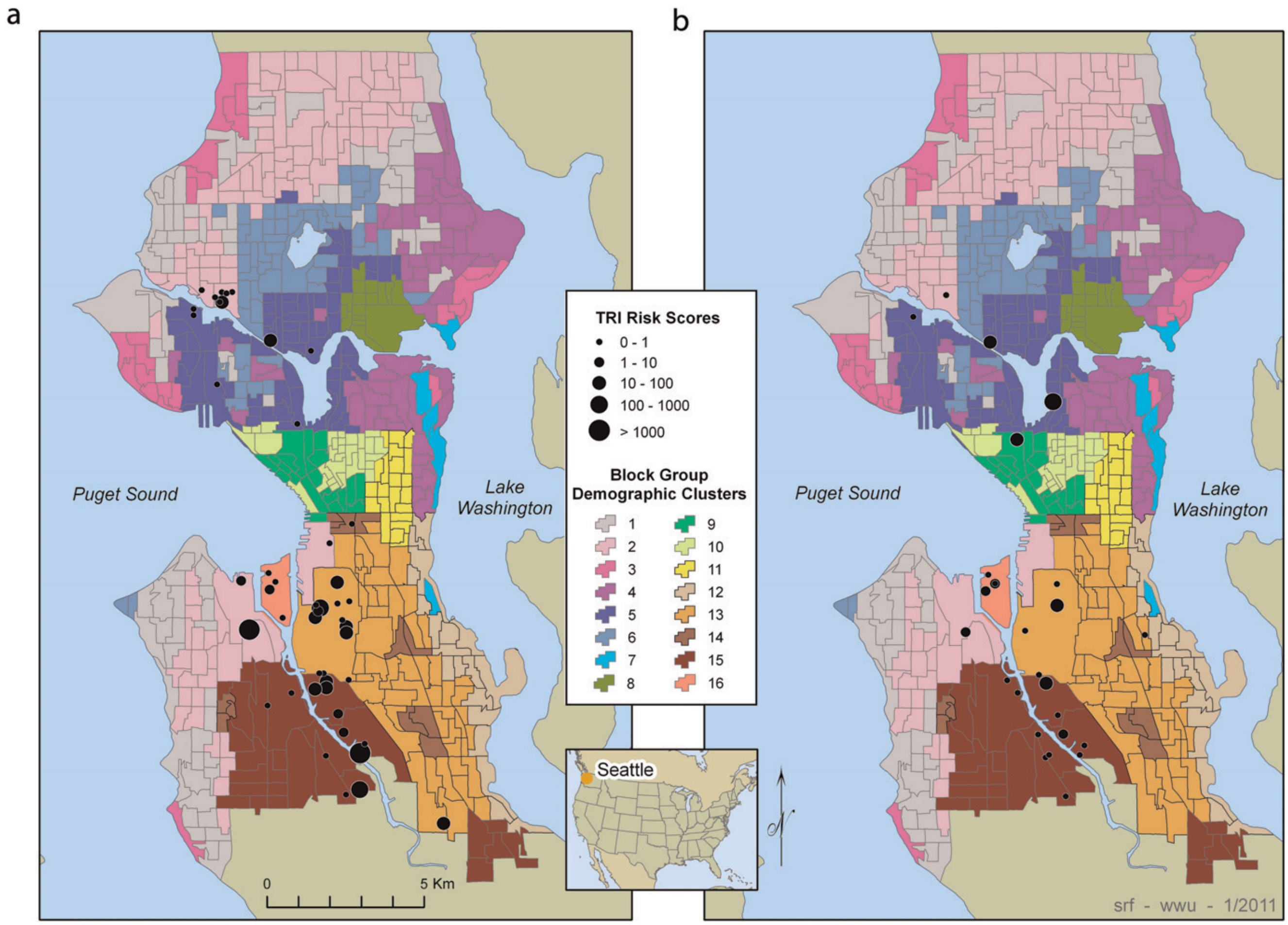
RESULTS

We first plotted the spatial location of 90 TRI facilities and characterized the relative risk of their simulated inhalation exposures with air emissions in 1990, 2000, and 2007 from all facilities reporting from 1990 to 2007 (Figures 1 and 2). Table 1 displays the relative risk indicator values for the 10 most hazardous air pollution sources in Seattle for 1990, 2000, and 2007, and then for all years. Air pollution volume dropped dramatically from over 2 million pounds in 1990 to 38 000 pounds in 2007. The relative risk scores also decreased from over 30 million to less than one million in 2000. However, the risk score increased to over 1 million in 2007. Six TRI facilities in 1990 and 7 in 2000 produced 99% of Seattle's relative air toxic risk exposure. Only 1 facility in 2007 accounted for 95% of the city's relative risk burden. Over the 18-year study period, 10 facilities were characterized as responsible for 96% of Seattle's toxic risk exposure simulated from air pollution releases. To map sites by their relative risk scores, the absolute values were divided by 1000 to create 5 classes of facilities. These results revealed Seattle's skewed exposure riskscape and confirmed the first hypothesis.

Factorial Social Ecology

Figure 1 displays a 16 cluster characterization of Seattle's shifting socioeconomic strata, whereas Figure 2 simplifies the city's socioeconomic structure into areas of gentrifying and nongentrifying neighborhoods. Principal components analysis on Seattle's 1990 census block group data yielded a 3-factor solution reminiscent of applied factorial social ecology studies.[71–75] Its 3 factors included socioeconomic status, race/ethnicity, and household structure, which explained about 73% of the variance in Seattle census block groups. The socioeconomic factor produced high loadings on percentage of college graduates, percentage of professional occupations, median household income, median contract rent, and median house value. With strong positive loadings, this factor was indicative of a structural divide between the creative and working classes in Seattle. In the second factor, racial divides manifested with the percentage of Whites alone inversely related to Blacks or Asians alone, and the percentage at or below the poverty level. The third factor highlighted a divide between traditional home-owning families and younger, unrelated residents who valued urban living and amenities. The percentage of population aged 25–34 years was loaded together with nonfamily households, whereas both were inversely correlated to median household income and homeownership rates.

In the 2000 PCA, the results were consistent with more recent literature that identified just 2 factors reflecting an urban structure shaped mostly by socioeconomic status and household structure. Accounting for 65% of the variance in the arrangement of Seattle's urban landscape, the first factor represents a convergence of socioeconomic status and ethnicity. Factor 1 produced positive loadings for the percentage of college graduates, percentage of professional employment, median household income, median contract rent, median house value, and percentage of Whites. Items with negative loadings on factor 1 included percentage of Blacks alone, Asians alone, and residents at or below the poverty line. This structure reflected a continuing divide between the labor forces, yet the individual importance of median household income, median contract rent, and median house value was superseded by college graduates and professional occupation. Therefore, the more important driver of Seattle's spatial arrangement in 2000 shifted to its creative class.[76] Factor 2 was identical to factor 3 from 1990 and indicated that urban amenities continued to be significant in the city's structural form. The combination of 1990 and 2000 factors was used in a hierarchical cluster analysis of Seattle's census block groups.



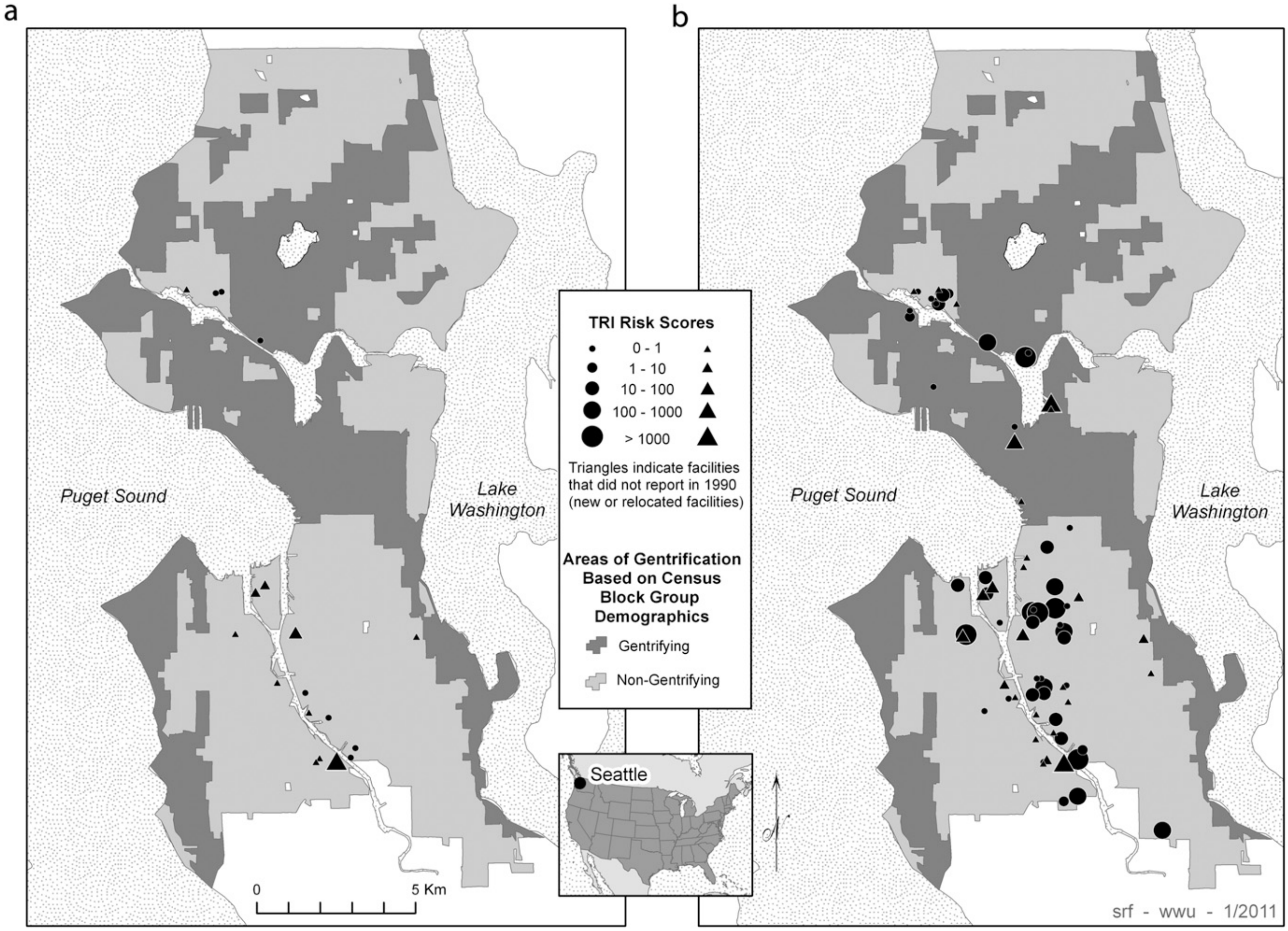
Source: Environmental Protection Agency's Risk Screening Environmental Indicators Model (Version 2.3); *Census CD 1990 Long Form in 2000 Boundaries*. US Census 2000.[41,57,58]

FIGURE 1—Toxics release inventory (TRI) facility risk characterizations and geographic clusters in (a) 1990 and (b) 2000.

Cluster Analysis

The results of the cluster analysis yielded census block groups with similar values on the 5 factors derived from the PCA analyses. Like Morrill,[56] multiple cluster solutions were explored, and a 15-cluster solution was found to be the most coherent ordering of Seattle's urban structure considering quantitative relationships as well as historical geographies of locally recognized neighborhoods. Figures 1 and 2 show these 16 clusters layered with the TRI facilities reporting in 1990 and 2000. Cluster 16 was excluded from statistical estimations because it encompassed the industrial district of Harbor Island at the mouth of the Duwamish River and contained no residences. Clusters 1 and 2 were dispersed throughout the city and represented predominately upper middle class family households. Clusters 3, 4, and 7 captured some of the most affluent neighborhoods and their coveted viewsheds. Clusters 5 and 6 were neighborhoods dominated by young urban professionals. Cluster 8 was the most concentrated and compact neighborhood, encompassing the city's largest higher educational institution, the University of Washington. Clusters 9 and 10 encompassed the Central Business District. The second most concentrated and compact cluster was 11, representing a historically African American neighborhood regionally known as the Central District. Cluster 12 was another viewshed grouping containing upper class residential homes. Cluster 13 was the most diverse and dominated by lower middle class residents. The least affluent residents were found in cluster 14, whereas cluster 15 was mostly a working class neighborhood intertwined with Seattle's industrial district.

Using an earlier typology devised by Morrill,[56] 15 of 16 clusters were assigned to 1 of 3 gentrification patterns in Seattle (redevelopment, replacement, and displacement) and 2 other trajectories (transition and consolidation; see box on page S251). The redevelopment form was described as traditional downtown resurgence through a combination of public and private efforts to (re)create upscale housing conditions and retail activities in or near the downtown core of the city. Replacement was driven by the lifestyle concerns of young, college-educated, and professional class residents who were generally unmarried. Displacement was considered the traditional form of gentrification, where Whites displaced non-White households, or



Source: Environmental Protection Agency's (EPA's) TRI Database; EPA's Envirofacts Database; EPA's Risk Screening Environmental Indicators Model (Version 2.3); *Census CD 1990 Long Form in 2000 Boundaries*; US Census 2000.[41,57,58]

FIGURE 2—Toxics release inventory (TRI) facility risk characterizations and gentrification areas in (a) 2007 and (b) 1990–2007.

wealthier classes overtook poorer classes. Transition clusters experienced little change in socioeconomic status but encountered population turnover and the mixing of Whites, Blacks, and Asians. Consolidation clusters contained the wealthiest and most affluent residents in both 1990 and 2000 without significant population turnover or mixing. Figure 2 shows a backdrop of Seattle's clusters simplified into gentrified and nongentrified areas.

Seven of Seattle's 15 clusters experienced gentrification, which confirmed the second hypothesis. The city's spaces of affordable housing decreased between 1990 and 2000. One observer described how,

> the ever-increasing concentration of wealth could mean Seattle will become more and more the gilded city of the upper middle and upper classes.[77(p236)]

However, a closer look at cluster 15 in Table 2 revealed an opposite trend, as the area became one of Seattle's outliers. Although the number of residents below poverty did not increase, this working class neighborhood transformed into a majority of non-Whites, increasing from 37.5% to 53.4% between 1990 and 2000. The cluster also had an increase in Black residents, whereas most clusters in the city lost African Americans. Asians increased at a faster rate in cluster 15. This area also had other notable contrasts with the rest of the city.

Median household income remained below city averages in 1990 and 2000. Median house values increased at nearly the same rate as the rest of the city (38.39% and 39.68%), but cluster 15 homes were \$100 000 below the median value of a Seattle home. This cluster's lack of college graduates and professional workers compared with the rest of the city increased from 23.6% to 26.6% and 20.4% to 21.9%, respectively. Cluster 13 displayed a similar class contrast with the rest of the city while hosting a much larger share of Asian alone residents and a slightly higher average home value than cluster 15. Both clusters had slightly higher poverty rates than the rest of the city. Table 1 also provides an accounting of the environmental inequality experienced in these areas. Cluster 13 had 50% of the air toxic exposure risk in 1990, whereas cluster 15 contained the 1 facility responsible for 95% of the city's pollution risk production in 2007.

TABLE 2—Cluster Descriptions and Mean Values of Variables (1990–2000) for Seattle City, Cluster 13, and Cluster 15.

	Seattle			Cluster 13			Cluster 15		
Variables	1990	2000	Change	1990	2000	Change	1990	2000	Change
White alone, %	75.93	71.78	–4.15	24.90	21.93	–2.97	62.51	46.56	–15.95
Black alone, %	10.21	8.14	–2.07	28.61	20.96	–7.65	12.51	14.49	1.98
Asian alone, %	11.19	12.55	1.36	43.37	45.61	2.24	18.97	22.14	3.17
College graduates, %	37.91	47.19	9.28	15.98	22.35	6.37	14.29	20.58	6.29
Professional/managerial, %	36.27	48.41	12.14	18.08	27.20	9.12	15.91	26.51	10.60
Age 25–34 y, %	21.73	21.71	–0.02	18.29	16.83	–1.46	19.75	17.40	–2.35
Median household income, $	43 872	45 736	4.25	35 904	42 051	17.12	38 898	42 427	9.07
Median contract rent, $	633	721	13.90	508	594	16.93	560	687	22.68
Median house value, $	185 857	259 600	39.68	114 687	179 782	56.76	109 210	151 131	38.39
Nonfamily households, %	12.20	14.58	2.38	6.24	9.12	2.88	9.16	10.53	1.37
At or below poverty, %	12.38	11.79	–0.59	16.66	14.14	–2.52	13.11	12.47	–0.64
Owner-occupied, %	48.87	48.41	–0.46	57.25	58.34	1.09	58.80	59.24	0.44

Finally, these 2 clusters had 68% of Seattle's cumulative air toxic pollution exposure risks between 1990 and 2007. The third hypothesis that pollution risk and inequitable development converged in the same place was supported.

Gentrification also seemed to influence the locations of new or relocating industrial facilities during the 18-year study period. Figure 2 labels new or relocating facilities after 1990 with a triangle symbol. In 2007, 11 new facilities reported to the TRI and none of them were in a gentrifying area. In particular, the historically industrial north central part of the city known locally as Ballard had 11 TRI facilities in 1990. The area had only 3 new facilities during the 18 years of this study. Conversely, 14 new or relocated facilities operated in clusters 13 and 15 after 1990, whereas only 2 appeared around Lake Union's "replacement" cluster 5, 2 in the downtown "redevelopment" clusters 9 and 10, and 2 on Harbor Island.

DISCUSSION

Seattle's urban geography underwent a significant transformation from 1990 to 2007. The city continued its post-industrial shift as Seattle lost two thirds of its 1990 industrial footprint. Consequently, industrial air pollution volume decreased 99% and the simulated relative exposure risk of Seattle's TRI air emitters also decreased by 96%. One dimension of the city's environmental condition was convincingly cleaner and greener. However, this overall summary, which was similar to portrayal of average environmental inequities, overlooked the extreme pollution cases. A closer analysis of high exposure risk facilities and their proximity to socially vulnerable neighborhoods shed a different light onto Seattle's riskscape.

In 1990, 7 of the city's 10 riskiest air polluters were located in the same clusters where minority populations increased and economic development lagged behind the rest of the city. In the next decade, Seattle's riskscape decreased and the highest relative exposure risk sources were more dispersed across the city. This trend reversed by 2007, however, and industry's relative exposure risk increased when the pollution volume was a quarter of the city's 2000 level. Moreover, 95% of industry's relative air toxics exposure risks were attributed to just 1 facility. As noted by Bouwes et al.,

> . . . a single pound of the most toxic chemicals . . . [can be] toxicologically equivalent to one hundred million pounds of the least toxic of these substances.[78(p4)]

The science of environmental health disparities should account for these extremes of pollution exposure risk.

Likewise, and as advocated by participants in a recent land-use and public health workshop, research must incorporate methods to examine how built environments change over time.[79] Seattle's postindustrial ascendance became evident in the increasing levels of college graduates and professional/managerial employment from 1990 to 2000. On average, the former increased from 37.9% to 47.2% and the latter from 36.3% to 48.4%. Conversely, clusters 13 and 15 were home to half as many White collar professionals and college graduates. Although the income differences in clusters 13 and 15 were only slightly lower, there was a substantial gap in accumulated wealth as measured in median household income. Homes in cluster 13 were only 70% as valuable as the average Seattle home,

Cluster Descriptions

1: Gentrification "replacement"–increased social status; above average incomes; above average ownership
2: Transition–increasing social status; young, nonfamilies; increasing minorities; middle income
3: Consolidation–high social status; high income; high house value
4: Consolidation–high social status; high income; high house values; mild displacement
5: Gentrification "replacement"–above average social status; increased young nonfamilies; increased incomes; renters
6: Gentrification "replacement"–above average social status; increased young nonfamilies; increased incomes; owners
7: Consolidation–highest social status; highest house values; notable displacement
8: Transition–University district; numerous college-educated professionals and young nonfamilies in poverty
9: Gentrification "core redevelopment"–increasing social status; increased young population; increasing incomes; housing inflation
10: Gentrification "core redevelopment"–increased social status; increased young nonfamilies; increased income
11: Gentrification "displacement"–increasing social status; increased young nonfamilies; high displacement and housing inflation
12: Gentrification "displacement"–increased social status; increased incomes; high displacement and housing inflation
13: Transition–Asian influx; little change in status (working class); above average ownership
14: Transition–Asian influx; little change in status (least affluent); concentrated poverty; negative income growth
15: Transition–minority mixing; little change in status (working class); above average ownership

and cluster 15 homes only 58% the value of the city's average owner-occupied dwelling. In summary, gentrification transformed the city into a more divided geography of class, and to a lesser extent, by race. The geographic and historical analysis of Seattle's socioeconomic strata revealed another overlooked dimension that health disparity and environmental justice research should consider.

Finally, the riskiest industrial facilities and the lowest socioeconomic strata in this longitudinal study converged early and late in the same places. The analysis illuminated how Seattle de-industrialized, but also saw the burdens of its remaining industrial facilities fall disproportionately on some of the city's most socially vulnerable populations. The riskiest and most new TRI facility sitings were in clusters 13 and 15 during the 18 years covered by this study. The proximity of Seattle's riskiest air toxic emission sources to socially vulnerable clusters represented an overlooked environmental health disparity. The combined application of the environmental science of relative risk screening and geographic social science in a longitudinal framework revealed Seattle's complicated yet intersecting trajectories of environmental inequality and socioeconomic stratification. Such historical considerations will be crucial input in the needed and much larger research task integrating the determinants of environmental, socioeconomic, and health inequity.

Limitations

This research had several limitations. First, the RSEI risk characterizations were based on TRI data. The information was self-reported, and the EPA lacked sufficient resources to extensively audit industry numbers. The EPA also acknowledged that the use of release estimates instead of monitored data were widespread. Facility estimates might be more or less than actual release amounts. However, no other reliable and historical database of localized pollution exposure existed. Second, the RSEI risk characterizations were model simulations instead of actual monitored air toxics concentrations. Only 23 federal air toxic monitoring stations and 300 state sites existed in 2005 according to the EPA's Office of Inspector General.[80] Moreover, the only 4 ambient air toxic monitors located in the 50 census tracts were in areas with the highest estimated cancer risk in the United States; therefore, urban air toxics riskscapes like Seattle's were poorly characterized.

Second, the approach to gentrification was informed more by urban geography than by public health or the growing field of social vulnerability. Therefore, the components did not include socioeconomic status measures more common in the determinants of health literature. For instance, the modified Darden-Kamel Socioeconomic Status (SES) composite index included a measure of vehicle ownership and the Krieger Socioeconomic Position Composite indexed percentages of working class, unemployment, low education, and expensive homes.[81,82] However, this study agreed with Darden et al., who observed that

> . . . not only are health disparities related to the SES and race of population groups but that such disparities are also place based. . .[83(p155)]

While the strata used here were a compilation of different variables, the clustering methods in this study could better localize different indices.

Conclusions

Literature on environmental injustice and health disparities found that spatial distributions of pollution hazards and socially vulnerable populations were clustered together in metropolitan areas. Far fewer studies examined how skewed these exposure riskscapes could be as well as how environmental inequalities were formed. Seattle has been heralded for its leadership in sustainability, but this analysis questioned this reputation. Parts of the city fared poorly in all 3 dimensions of sustainability—environment, equity, and economy. Environmental and socioeconomic inequality has always been a feature of Seattle's geography,[84] and these methods revealed how the city's pollution exposure risks changed between 1990 and 2007. This study also found that the city's neighborhoods were divided more sharply along socioeconomic lines. Finally, this study found that pollution exposure risk and lower socioeconomic clusters converged in the same place. According to a *Seattle Times* analysis,

> the only area in Seattle where median-income folks could afford the median-priced house was the residential/industrial/commercial swath south of downtown that includes Georgetown and South Park.[85(pB1)]

Seattle's pollution riskscape and urban development burdens were skewed toward the city's most socially vulnerable residents.

Not all pollution is created, nor is exposure to it uniformly equal in a dynamic urban landscape. The methodological combinations we used informed the future science of environmental health disparities and provided the methods to examine the convergence of skewed exposure risks and gentrified inequities. The study also provided a way to bridge the fields of urban geography and public health. Understanding the geography of environmental exposure disparities and socioeconomic cleavages has implications for zoning, affordable housing, environmental, and public health policies. Utilizing these methods could better inform public health researchers and practitioners where to assist industry with pollution prevention, where to perform cumulative health assessments, and where to initiate larger and more integrated investigations into the complex intersections of environmental inequality, socioeconomic divisions, and health disparities. ■

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This article was accepted February 7, 2011.

Contributors

T. D. Abel originated the study, conducted the relative risk screening exposure modeling, and led the writing of the article. J. White designed and conducted the statistical factor and cluster analyses and contributed to the writing of the article.

Acknowledgments

This research was supported by Western Washington University's Research and Sponsored Programs and

Huxley College of the Environment's Institute for Spatial Information and Analysis.

Earlier versions of this article were presented at the 2009 annual meetings of the Association of American Geographers and the Association of Pacific Coast Geographers.

We thank Stefan Freelan, Debnath Mookherjee, Debra Salazar, Andrew Bodman, Daniel Kostek, Ben Kane, Michelle Munn, and Lynne Blake-Hedges, participants in the US Environmental Protection Agency's conference "Strengthening Environmental Justice Research and Decision Making: A Symposium on the Science of Disproportionate Environmental Health Impacts"; this supplement's editors, Devon Payne-Sturges, Onyemaechi Nweke, and Irene Dankwa-Mullen; and 2 anonymous reviewers for their helpful support and suggestions.

Human Participant Protection

This research involved no human subjects.

Selected References

1. Bowen WM, Salling MJ, Haynes KE, Cyran EJ. Toward environmental justice: spatial equity in Ohio and Cleveland. *Ann Assoc Am Geogr.* 1995;85(4):641–663.

2. Boer JT, Pastor M Jr, Sadd JL, Snyder LD. Is there environmental racism? The demographics of hazardous waste in Los Angeles County: research on the evironment. *Soc Sci Q.* 1997;78(4):793–810.

3. Bullard RD. Solid waste sites and the Black Houston community. *Sociol Inq.* 1983;53(2/3):273–288.

4. Dolinoy DC, Miranda ML. GIS modeling of air toxics releases from TRI-reporting and non-TRI-reporting facilities: impacts for environmental justice. *Environ Health Perspect.* 2004;112(17):1717–1724.

5. Fisher JB, Kelly M, Romm J. Scales of environmental justice: combining GIS and spatial analysis for air toxics in West Oakland, California. *Health Place.* 2006;12:701–714.

6. Pastor M Jr, Sadd JL, Morello-Frosch R. Who's minding the kids? Pollucion, public schools, and environmental justice in Los Angeles. *Soc Sci Q.* 2002;83(1):263–280.

7. Pulido L, Sidawi S, Vos R. An archaeology of environmental racism in Los Angeles. *Urban Geogr.* 1996;17:419–439.

8. Sicotte D, Swanson S. Whose risk in Philadelphia? Proximity to unequally hazardous industrial facilities. *Soc Sci Q.* 2007;88(2):515–534.

9. Office of Environmental Justice, U.S. Environmental Protection Agency, *Environmental Justice: 2000 Biennial Report: Continuing To Move Towards Collaborative and Constructive Problem-Solving.* October, 2001.

10. United Church of Christ. *Toxic Wastes and Race: A National Report on the Racial and Socioeconomic Characteristics of Communities with Hazardous Waste Sites.* New York: United Church of Christ Commission for Racial Justice; 1987.

11. Bowen WM. *Environmental Justice Through Research-Based Decision-Making.* New York: Garland Publishing; 2001.

12. Foreman CH Jr. *The Promise and Peril of Environmental Justice.* Washington, D.C.: Brookings Institution Press; 1998.

13. Lester JP, Allen DW, Hill KM. *Environmental Injustice in the United States: Myths and Realities.* Boulder, CO: Westview Press; 2001.

14. Ringquist E. Environmental justice: normative concerns, empirical evidence, and government action. In: Vig NJ, Kraft ME, eds. *Environmental Policy: New Directions for the Twenty-First Century.* 6th ed. Washington, DC: CQ Press; 2006.

15. Abel TD. Skewed riskscapes and environmental injustice: a case study of metropolitan St. Louis. *Environ Manage.* 2008;42(2):232–248.

16. Been V. Locally undesirable land uses in minority neighborhoods: disproportionate siting or market dynamics. *Yale Law J.* 1994;103(6):1383–1422.

17. Been V, Gupta F. Coming to the nuisance or going to the barrios? A longitudinal analysis of environmental justice claims. *Ecol Law Q.* 1997;24(1):1–56.

18. Graham JD, Beaulieu ND, Sussman D, Sadowitz M, Li Y- C. Who lives near coke plants and oil refineries? An exploration of the environmental inequity hypothesis. *Risk Anal.* 1999;19:171–186.

19. Lambert T, Boerner C. Environmental inequity: economic causes, economic solutions. *Yale J Regul.* 1997; 14(1):195–234.

20. Oakes JM, Anderton DL, Anderson AB. A longitudinal analysis of environmental equity in communities with hazardous waste facilities. *Soc Sci Res.* 1996;25(2): 125–148.

21. Pastor M Jr, Sadd J, Hipp J. Which came first? Toxic facilities, minority move-in, and environmental justice. *J Urban Aff.* 2001;23(1):1–21.

22. Richardson EA., Shortt NK, Mitchell RJ. The mechanism behind environmental inequality in Scotland: which came first, the deprivation or the landfill? *Environ Plan A.* 2010;42(1):223–240.

23. Stretesky P, Hogan MJ. Environmental justice: an analysis of superfund sites in Florida. *Soc Probl.* 1998; 45(2):268–287.

24. Yandle T, Burton D. Reexamining environmental justice: a statistical analysis of historical hazardous waste landfill siting patterns in metropolitan Texas. *Soc Sci Q.* 1997;77(3):477–492.

25. Metzler M. Social determinants of health: what, how, why, and now. *Prevg Chronic Dis..* 2007;4(4):1–4.

26. Morello-Frosch R, Shenassa ED. The environmental 'riskscape' and social inequality: implications for explaining maternal and child health disparities. *Environ Health Perspect.* 2006;114(8):1150–1153.

27. Holmes JH, Lehman A, Hade E, et al. Challenges for multilevel health disparities research in a transdisciplinary environment. *Am J Prev Med.* 2008;35(2, Suppl): S182–S192.

28. Braveman P. Health disparities and health equity: concepts and measurement. *Annu Rev Public Health.* 2006;27:167–194.

29. Mohai P, Lantz PM, Morenoff J, et al. Racial and socioeconomic disparities in residential proximity to polluting industrial facilities: evidence from the Americans' Changing Lives Study. *Am J Public Health.* 2009;99(S3): S649–S656.

30. Brulle RJ, Pellow DN. Environmental justice: human health and environmental inequalities. *Annu Rev Public Health.* 2006;27:103–124.

31. Ash M, Fetter TR. Who lives on the wrong side of the environmental tracks? Evidence from the EPA's risk-screening environmental indicators model. *Soc Sci Q.* 2004;85(2):441–462.

32. Gilbert A, Chakroborty J. Using geographically weighted regression for environmental justice analysis: cumulative cancer risks from air toxics in Florida. *Soc Sci Res.* 2011;40(1):273–286.

33. Linder SH, Marko D, Sexton K. Cumulative cancer risk from air pollution in Houston: disparities in risk burden and social disadvantage. *Environ Sci Technol.* 2008;42(12):4312–4322.

34. Morello-Frosch R, Pastor M, Sadd J. "Environmental justice and southern California's "riskscape": the distribution of air toxics exposures and health risks among diverse communities. *Urban Aff Rev.* 2001;36(4):551–578.

35. Kennedy M, Leonard P. *Dealing With Neighborhood Change: A Primer on Gentrification and Policy Choices.* Washington, DC: Brookings Institution Center on Urban and Metropolitan Policy and PolicyLink; 2001.

36. Buzzelli M, Jerrett M, Burnett R, Finklestein N. Spatiotemporal perspectives on air pollution and environmental justice in Hamilton, Canada, 1985–1996. *Ann Assoc Am Geogr.* 2003;93(3):557–573.

37. Callewaert J. The importance of local history for understanding and addressing environmental injustice. *Local Environ.* 2002;7(3):257–267.

38. Saha R, Mohai P. Historical context and hazardous waste facility siting: understanding temporal patterns in Michigan. *Soc Probl.* 2005;52(4):618–648.

39. Szasz A, Meuser M. 2000. Unintended, inexorable: the production of environmental inequalities in Santa Clara County, California. *Am Behav Sci.* 2000;43:602–632.

40. Corburn J. Confronting the challenges in reconnecting urban planning and public health. *Am J Public Health.* 2004;94(4):541–546.

41. *Risk Screening Environmental Indicators.* [computer program]. Version 2.3.0. Washington, DC: US Environmental Protection Agency. June 2010. Available at: http://www.epa.gov/oppt/rsei/pubs/get_rsei.html. Accessed June 28, 2010.

42. Glass R. Introduction: aspects of change. In Centre for Urban Studies (ed.) *London: Aspects of Change.* London: MacKibbon and Kee; 1964.

43. Hamnett C. The blind men and the elephant: the explanation of gentrification. *Trans Inst Br Geogr.* 1991; 16(2):173–189.

44. Ley D. Liberal ideology and the postindustrial city. *Ann Assoc Am Geogr.* 1980;70:238–258.

45. Smith N. Toward a theory of gentrification: a back to the city movement by capital, not people. *J Am Plann Assoc.* 1979;45(4):538–548.

46. Smith N. Gentrification. In: Johnston RJ, Gregory D, Pratt G, Watts M, eds. *The Dictionary of Human Geography.* 4th ed. Oxford, UK: Blackwell; 2000.

47. Ley D. *The New Middle Class and the Remaking of the Central City.* Oxford, UK: Oxford University Press; 1996.

48. Smith N. *The New Urban Frontier: Gentrification and the Revanchist City.* London: Routledge; 1996.

49. Wyly EK, Hammel DJ. Islands of decay in seas of renewal: housing policy and the resurgence of gentrification. *Housing Policy Debate.* 1999;10(4):711–771.

50. Cutter SL. Vulnerability to environmental hazards. *Prog Hum Geogr.* 1996;20(4):529–539.

51. Cutter SL, Boruff BJ, Shirley WL. Social vulnerability to environmental hazards. *Soc Sci Q.* 2003;84(2):242–261.

52. Eakin H, Luers AL. Assessing the vulnerability of social-environmental systems. *Annu Rev Environ Resour.* 2006;31:365–394.

53. Martin R. Geography and public policy: the case of the missing agenda. *Prog Hum Geogr.* 2001;25(2):189–210.

54. Murphy AB. Enhancing geography's role in public debate. *Ann Assoc Am Geogr.* 2006;96(1):1–13.

55. Brown S. 2002. Urban Institute Puts Neighborhoods under Analytical Microscope with New Database Spanning Four Censuses. Washington, DC: The Urban Institute. Available at: http://www.urban.org/url.cfm?ID=900555. Accessed September, 11, 2010.

56. United States Department of Commerce. *Geographic Areas Reference Manual.* Washington, DC: Economics and Statistics Administration, Division of Geography, Bureau of the Census; 1994.

57. *CensusCD 1990 Long Form in 2000 Boundaries.* East Brunswick, NJ; GeoLytics, Inc.; 2007.

58. US Census 2000. Washington, DC: US Census Bureau; 2002.

59. Harvey D. *The Condition of Postmodernity.* Oxford: Basil Blackwell; 1989.

60. Morrill R. Gentrification, class, and growth management in Seattle, 1990-2000. In: Pomeroy G, Webster G, eds. *Global Perspectives on Urbanization.* Lanham, MD: University Press of America; 2008.

61. Berry BL. Introduction: the logic and limitations of comparative factorial ecology. *Econ Geogr.* 1971; 47(Suppl 2):209–219.

62. Haynes K. Spatial change in urban structure: alternative approaches to ecological dynamics. *Econ Geogr.* 1971;47(2):324–335.

63. Janson C-G. Factorial social ecology: an attempt at summary and evaluation. *Annu Rev Sociol.* 1980;6:433–456.

64. Fischer CS, Stockmayer G, Stiles J, Hout M. Distinguishing the geographic levels and social dimensions of U.S. metropolitan segregation: 1960–2000. *Demography.* 2004;41(4):37–59.

65. Pacione M. *Urban Geography: A Global Perspective.* New York: Routledge; 2009.

66. Wyly EK. Continuity and change in the restless urban landscape. *Econ Geogr.* 1999;75(4):309–338.

67. Kim J-O, Mueller CW. *Factor Analysis: Statistical Methods and Practical Issues.* Beverly Hills, CA: Sage Publications; 1978.

68. Cadwallader M. *Urban Geography: An Analytical Approach.* Upper Saddle River, NJ: Prentice Hall; 1996.

69. Aldenderfer MS, Blashfield RK. *Cluster Analysis.* Beverly Hills, CA: Sage Publications; 1984.

70. Lattin JM, Carroll JD, Green PE. *Analyzing Multivariate Data.* Pacific Grove, CA: Thomson Brooks/Cole; 2003.

71. Shevky E, Bell W. *Social Area Analysis: Theory, Illustrative Application, and Computational Procedures.* Stanford, CA: Stanford University Press; 1955.

72. Abu-Lughod JL. Testing the theory of social area analysis: the ecology of Cairo, Egypt. *Am Sociol Rev.* 1969;34(2):198–212.

73. Berry BJL, Rees PH. The factorial ecology of Calcutta. *Am J Sociol.* 1969;74(5):445–491.

74. Berry BJL. Islands of renewal in seas of decay. In: Peterson PE, ed. *The New Urban Reality.* Washington, DC: The Brookings Institution; 1985.

75. Schmid CF, Tagashira K. Ecological and demographic indices: a methodological analysis. *Demography.* 1964;1(1):194–211.

76. Florida R. *The Rise of the Creative Class.* New York: Basic Books; 2003.

77. McGee HW Jr. Seattle's central district, 1990-2006: integration or displacement. *Urban Lawyer.* 2007;39(2): 167–256.

78. Bouwes NW, Hassur SM, Shapiro MD. *Empowerment Through Risk-Related Information: EPA's Risk Screening Environmental Indicators Project.* Amherst, MA: Political Economy Research Institute; 2001.

79. Dannenberg AL, Jackson RJ, Frumkin H, et al. The impact of community design and land-use choices on public health: a scientific research agenda. *Am J Public Health.* 2003;93(9):1500–1508.

80. United States Environmental Protection Agency (EPA). *Progress Made in Monitoring Ambient Air Toxics, But Further Improvements Can Increase Effectiveness.* Washington, DC: Office of Inspector General; 2005.

81. Darden JT, Kamel SM. Spatial and socioeconomic analysis of Latin Americans and whites in the Toronto CMA. *J Dev Soc.* 2000;16(2):245–270.

82. Krieger N, Chen JT, Waterman PD, Rehkopf DH, Subramanian SV. Race/ethnicity, gender, and monitoring socioeconomic gradients in health: a comparison of area-based socioeconomic measures—the public health disparities geocoding project. *Am J Public Health.* 2003; 93(10):1655–1671.

83. Darden J, Rahbar M, Jezierski L, Li M, Velie E. The measurement of neighborhood socioeconomic characteristics and black and white residential segregation in metropolitan Detroit: implications for the study of social disparities in health. *Ann Assoc Am Geogr.* 2010;100(1): 137–158.

84. Klingle M. *Emerald City: An Environmental History of Seattle.* New Haven: Yale University Press; 2007.

85. Rhodes E, Mayo J. Only 9 areas in King County left for middle-income buyers. *Seattle Times.* July 16, 2006, B1.