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Supplementary Materials

Risky Business: Sustainability and Industrial Land Use Across Seattle's Gentrifying Riskscape. *Sustainability* 2015, *7*, 15718-15753

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1. The Principal Components of Seattle's Gentrification

To assess gentrification's presence and impacts in Seattle, we applied factor and cluster analysis to demographic information on Seattle's 568 Census Block Groups (CBGs) from the 1990 and 2000 censuses normalized by 2000 geographic boundaries [1] plus data from the 2009 American Community Survey (ACS). CBGs are built from census blocks and typically contain 600 to 3000 people while Census Tracts have between 1500 and 8000 residents bounded by visible features [2]. While we follow Morrill's [3] study of Seattle's trajectories of spatial socioeconomic change with a combination of Principal Components Analysis (PCA) and cluster analyses of census tracts, we use the finer resolution of CBGs. Using the same statistical methods of factorial social ecology [4–8], we explore how widespread gentrification occurs in Seattle. However, and consistent with Ley and Dobson [9], we also explored gentrification patterns near Seattle's industrial areas.

Factorial social ecology and its PCA form is designed to systematically reduce a large number of variables into a smaller, more conceptually coherent set of factors, dimensions, or components [10]. Variable groupings that exhibit intercorrelations are replaced in subsequent analysis by an unmeasured or latent variable. PCA techniques accomplish this by regressing observed variables on an unmeasured dimension called a component or factor. Three broad dimensions of urban structure (social status, family status, and ethnic status) have been consistently tested in PCA analysis of a wide range of urban studies including gentrification research on major Canadian cities [11,12], Baltimore [13], Brussels [14], Houston [15], and by scholars of US urban segregation [16–18]. For example, Ley utilized the (PCA) form of factor analysis in a study of 22 Canadian cities and identified three groupings of eight variables that represented a city's postindustrial status, an inner-city housing squeeze, and a quality-of-life dimension [19].

Likewise, in Morrill's [3] more recent study of Seattle, he described three dimensions of postindustrial gentrification dominating the city's transformation: redevelopment, displacement, and replacement.

We too relied principal components analysis (PCA) because it's an effective data reduction technique well-suited for the exploratory purpose of our Seattle study to distinguish gentrification from other types of neighbourhood change patterns [20–22]. Some combination of population, socioeconomic, and housing measures dominate gentrification research. Population measures usually encompass age racial/ethnic compositions and age structures [23,24] including children under 18 as a negative indicator of gentrification [25] and 25–34 young adults who have been described as the driving force in the new, creative, and postindustrial economy [26]. Other common gentrification indicators include metrics of income and poverty, education, and occupation [27,28] and housing measures like home prices and values, rents, ownership, and household structure [29]. Component scores from the three PCAs are then used as independent variables in a cluster analysis of similar CBGs.

2. Clusters of Gentrification

While factor analysis results in groupings of variables, cluster analysis groups objects based on characteristics of interest to an analyst [30]. We used Ward's method of cluster analysis and its minimum distance hierarchical technique to differentiate relative homogenous CBGs. This was the most appropriate technique for this research because of its maximization of between-group differences and minimization of within-group differences [31]. This method resulted in small sized clusters (as few block-groups as possible) with substantial homogeneity. Thus, block-groups that experienced significant change in the form of gentrification are well-differentiated from those that experienced other trajectories.

For example, a cluster analysis of Chicago census tracts between 1970 and 1990 led researchers to classify four distinct types of neighbourhood change: (1) stable middle-class; (2) gentrifying yuppie; (3) transitional working-class; and (4) ghetto underclass [32]. Similarly, Morrill's [3] Seattle study of census tracts revealed eleven clusters of neighbourhood change across five types: (1) gentrification-redevelopment; (2) gentrification-displacement; (3) gentrification-replacement; (4) transition; and (5) decline in status. The three types of gentrification clusters were thus well distinguished from the other non-gentrification patters of change (transition and decline). Other researchers have utilized cluster analysis to examine gentrification and migration in US rural areas [33], urban immigrant neighbourhoods [34], and neighbourhood changes across metropolitan America [35,36].

The results of the cluster analysis yielded groupings of CBGs with similar values on the seven factors derived from our PCA analyses. Like Morrill [3], we explored multiple cluster solutions and found a 15-cluster solution to be the most coherent ordering of Seattle's urban structure considering quantitative relationships as well as historical geographies of locally recognized neighbourhoods (see Table S1). A sixteenth cluster was excluded from statistical estimations because it encompassed the industrial district of Harbor Island at the mouth of the Duwamish River containing no residences. Clusters 1, 2, and 5 were dispersed throughout the city and represented areas of increased professional status and affluence while also completely encompassing two of our three case study areas, BINMIC and SLU. The most affluent neighbourhoods composed clusters 4, 6, and 7. Cluster 3 included neighbourhoods with changing population compositions and household structures primarily in North Central Seattle.

Cluster 8 is one of the most concentrated and compact areas encompassing the city's largest higher educational institution, the University of Washington, and its concentrations of student housing. Clusters 9 and 11 covered downtown and the Central Business District (CBD) and exhibited significant increases in home values. Cluster 10 was another upper class residential area and Cluster 12 encompassed a historically African-American neighbourhood regionally known as the Central District [37]. Clusters 13 and 14 were racially mixed neighbourhoods dominated by lower middle class residents with low professional status. Cluster 15 was a racially diverse working class neighbourhood intertwined with the lower reaches of the GDMIC industrial area. Seven of Seattle's fifteen clusters experienced gentrification including two of our three industrial areas.

One part of cluster 1 enveloped the city's Green Lake in North Central Seattle while also stretching East and West into coveted view sheds of Elliott Bay and Lake Washington. The second and third blocks of cluster 1 encompassed the view sheds offered on top of the city's Queen Anne Hill and West Seattle's Alkai beach. This cluster's Median Household Income was the fourth richest in 2009 with a nearly five percent increase in 25 to 34 year old residents. Cluster 1 also climbed into second place for the largest share of Seattle's professional and managerial class (nearly 63 percent). Cluster 2 covered a significant area of Ballard and the BINMIC industrial area while increasing in its share of 25–34 year olds with lower household incomes and home values than the city average. Also, this cluster's percent professional and managerial occupations were well below the city average suggesting a cluster dominated by renters new to the workforce. Cluster 5 is striking because it envelops Lake Union just north of downtown with an increase in young and nonfamily households. The cluster also moved from below the average median household income in 1990 to above it in 2000 and 2009. It climbed to fourth place in the city for college graduates while also seeing one of Seattle's biggest surges (nearly 20 percent) of residents with professional and managerial occupations. These replacement gentrification clusters all had a significant class shift but changed little by race. Conversely, Cluster fifteen's trajectory in the center of the GDMIC industrial area was vastly different.

Table S1. Gentrification typology.

	Consolidation Clusters
4	High social status; high income; high home ownership rate; high average home values
6	High social status; high income; above average home ownership; high average home values
7	Highest social status; highest average home values; high home ownership rate; notable displacement
	Transition Clusters
3	Increasing social status; middle income; young, non-families; increasing minorities
8	University District; college-educated professionals; young, non-families in poverty
13	Asian influx; little change in social status (working-class); above average home ownership
14	Asian influx; low social status (working-class); high poverty; low home ownership
15	Minority mixing; little change in social status (working-class); above average home ownership
	Replacement Gentrification Clusters
1	Increased social status; above average incomes; increase in non-families; above average home values; above average home ownership
2	Increasing social status; increase in young, non-families; primarily renters
5	Increased social status; above average incomes; young, non-families; above average home values; primarily renters

Table S1. *Cont.*

	Core Redevelopment Gentrification Clusters
9	Increased social status; increase in young population; increasing income; increased home values; reduced poverty
11	Increasing social status; increased young, non-families; increased home values
	Displacement Gentrification Clusters
10	Increased social status; high income; reduced poverty; high home values; loss of Black population
12	Increasing social status; increasing income; increase in young, non-families; reduced poverty; loss of Black population (Central District)

Median household income in Cluster 15 remained below the city average in 1990, 2000, and 2009. While poverty declined between 1990 and 2000, it climbed from 12.3% to 15.8% between 2000 and 2009. Median house values increased at a higher rate than for the rest of the city (131.6% and 86.8%) but remained more than one hundred thousand dollars below the median value of a Seattle home. Cluster 15's gap of college graduates compared to the rest of the city increased between 1990 and 2009. Seventeen percent of Cluster 15 held a college degree in 1990 while 37.9% was the city average (20.9% difference). In 2009, 30.5% of Cluster 15 residents held a college degree while the city average was 54.3% (a 23.8% difference).

3. Characterizing Seattle's Evolving Riskscape

We also collected and analyzed data to characterize Seattle's industrial riskscape and its dynamics with two datasets to explore a second hypothesis that Seattle's industrial air toxic exposure risk would be unevenly dispersed. First, the spatial location of the city's 113 Toxics Release Inventory (TRI) facilities reporting air pollution emissions were plotted in 1990, 2000, and 2009. TRI facilities include all industrial firms that are required by the EPA to voluntarily report the release of any toxic chemical into the environment if (1) it is in the following industrial sectors—manufacturing, metal mining, coal mining, electrical utilities, hazardous waste treatment and disposal facilities, chemical plants, petroleum plants and terminals, solvent recovery services, and federal facilities; (2) has 10 or more full-time employees; and (3) manufactures or processes more than 25,000 pounds or otherwise uses more than 10,000 pounds of any listed chemical during the calendar year. We also examined the relative-risk posed by these facilities using data that simulated comparative inhalation exposures with the US Environmental Protection Agency's (EPA) Risk-Screening Environmental Indicators (RSEI) modeling program. Using self-reported TRI air release estimates, RSEI simulates a steady-state Gaussian plume of downwind pollutant concentrations from both stack and fugitive emission levels. RSEI than estimates a surrogate inhalation dose for neighboring census populations and produces a unit-less indicator value that can be used to rank relative impacts by geography, industry, and facility [38,39].

This part of our analysis joins a growing literature that utilizes RSEI to identify potential toxic hotspots and their proximity to socially vulnerable communities [40–47]. Conversely, the majority of environmental justice studies only crudely examine the proximity of industrial environmental hazards and socially vulnerable populations. Proximity and even release amounts reveal little about widely varying chemical emission toxicities for pollution buried in landfills or release from smokestacks. As one group of EPA researchers noted, "The human health impacts of carcinogens and noncarcinogens...

can differ by up to seven and eight orders of magnitude" [48]. Because not all pollution is created equally, inattention to the location of sources with skewed relative-risk potential can undermine effective responses to environmental injustice [49].

Second, we also plot the locations of facilities generating and managing hazardous waste between 2001 and 2013 to widen the characterization of Seattle's riskscape. The EPA's Biennial Reporting System (BRS) inventories information about Large-Quantity Generators (LQGs) that manage at least 1000 kilograms of hazardous waste monthly [50]. While recent studies utilizing the BRS have focused on regulatory compliance [51], inspections [52], and indirect regulation through markets [53], few examine their spatial proximity to socially vulnerable communities.

Table S2 displays the air pollution volume and the relative-risk indicator values for the Toxics Release Inventory (TRI) facilities reporting toxic air emissions in Seattle for 1990, 2000, 2009. In the beginning of our study period, Cluster thirteen's PSF industries is characterized in our RSEI simulations as Seattle's riskiest polluter and accounted for nearly half (49.01 percent) of the city's air toxic inhalation exposure risk while only releasing just over seven-thousand pounds of air pollution. Seattle's second worst TRI polluter in 1990 was the American Tar Company with releases of just over one-thousand pounds of air emissions that accounted for 38.24 percent of the city's relative air toxic risk exposure.

Table S2. Air pollution exposure risk source characterizations for Seattle's Toxic Release Inventory (TRI) facilities in 1990, 2000, 2009, and from 1990 to 2009.

1990				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
PSF INDUSTRIES INC.	13	7205	14,958,861	49.0%
AMERICAN TAR CO.	5	1255	11,670,515	38.2%
BOEING COMMERCIAL AIRPLANE GROUP PLANT 2	15	1,070,553	1,740,279	5.7%
SEATTLE STEEL INC.	3	44,100	1,395,724	4.6%
PRECISION ENGINEERING INC.	15	250	211,857	0.7%
WESTERN STEEL CASTING CO.	13	1500	171,021	0.6%
DIETZGEN CORP.	13	2470	72,246	0.2%
NORTH STAR CASTEEL PRODUCTS INC	13	1000	67,406	0.2%
NORTHWEST PLATING CO.	13	37,970	48,096	0.2%
ASKO PROCESSING INC	5	16,291	36,669	0.1%
INDUSTRIAL PLATING CORP.	13	27,541	35,994	0.1%
ART BRASS PLATING INC.	15	39,329	32,446	0.1%
CAPITAL INDUSTRIES INC	15	96,152	23,018	0.1%
ASKO PROCESSING INC. COLOR TECH. DIV.	3	18,134	15,603	0.1%
A. O. SMITH WATER PRODUCTS CO.	13	43,000	11,701	0.0%
SAINT-GOBAIN CONTAINERS INC.	15	5	10,895	0.0%
PACIFIC SOUND RESOURCES	3	160,914	4183	0.0%
TRIM SYSTEMS	15	11,646	3106	0.0%
NORTHWEST CASTINGS	13	250	2802	0.0%
VIOX CORP	15	500	1345	0.0%

Table S2. *Cont.*

1990				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
FABRICATED PRODS. INC. (DBA SEAFAB METALS CO.)	3	418	1000	0.0%
RUDD CO INC—changed Fac ID at same location	3	24,705	969	0.0%
EQUILON ENTERPRISES LLC SEATTLE LUBRICANTS PLANT	3	1858	517	0.0%
TODD PACIFIC SHIPYARDS CORP.	3	63,385	231	0.0%
BALLARD BRASS & ALUMINUM	3	250	106.	0.0%
SCOTT GALVANIZING CO. INC.	2	99	99.7	0.0%
BOEING COMMERCIAL AIRPLANE GROUP NORTH BOEING FIELD	15	190,537	96.0	0.0%
DYNO BATTERY INC.	5	69	62.8	0.0%
NORTH COAST CHEMICAL CO. INC.	15	4250	53.1	0.0%
YOUNG CORP.	13	8170	43.8	0.0%
KELLY-MOORE PAINT CO.	13	7659	22.7	0.0%
AVTECH CORP.	5	11,600	21.1	0.0%
PROLIANCE INTERNATIONAL INC	15	101	15.9	0.0%
WESMAR CO. INC.	3	250	15.8	0.0%
STROH BREWERY CO. RAINIER BREWERY	13	1700	10.7	0.0%
ROMAC INDUSTRIES INC.	15	1	9.96	0.0%
GM NAMEPLATE INC.	5	19,664	3.81	0.0%
RUDD CO INC—changed Fac ID at same location	3	323	3.74	0.0%
MAMCO MANUFACTURING INC.	3	15,387	3.10	0.0%
MACHINISTS DSR INC (DBA PUGET SOUND COATINGS)	15	6700	0.96	0.0%
KORRY ELECTRONICS CO.	5	5000	0.69	0.0%
ASAHIPEN AMERICA INC	3	500	0.57	0.0%
MARCO SEATTLE SHIPYARD	5	500	0.54	0.0%
PROLER RECYCLING INC.	15	1	0.52	0.0%
SKYLINE ELECTRIC & MFG. CO.	13	2230	0.29	0.0%
ALASKAN COPPER WORKS	13	5	0.24	0.0%
FORMULA CORP.	15	5	0.15	0.0%
CZS ENT. DBA COWMAN CAMPBELL	2	5	0.01	0.0%
GE CO. AIRCRAFT ENGINES	15	60	0.01	0.0%
SEATTLE TECHNICAL FINISHING INC	14	0	0.00	0.0%
Total of all facilities (n = 50)		1,945,497	30,517,070	
2000				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
SOUND PROPELLER SERVICES LAKE UNION	5	500	640,879	70.8%
ALASKAN COPPER WORKS	13	30	86,877	9.6%
WESCOR GRAPHICS CORP.	9	18,240	63,903	7.1%
ASKO PROCESSING INC	5	9925	50,952	5.6%
ART BRASS PLATING INC.	15	17,820	46,732	5.2%
NUCOR STEEL SEATTLE INC	3	45,224	7457	0.8%
EQUILON ENTERPRISES LLC EQUILON SEATTLE TERMINAL	3	3004	2981	0.3%
BP WEST COAST PRODUCTS CO–SEATTLE TERMINAL	3	4110	1447	0.2%
VIOX CORP	15	238	791	0.1%

Table S2. *Cont.*

2000				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
BOEING COMMERCIAL AIRPLANE GROUP NORTH BOEING FIELD	15	32,602	672	0.1%
RUDD CO INC - changed Fac ID at same location	3	31,797	654	0.1%
NON-FERROUS METALS INC	15	255	577	0.1%
TODD PACIFIC SHIPYARD CORP	3	29,158	436	0.0%
BOEING COMMERCIAL AIRPLANE GROUP PLANT 2	15	2527	373	0.0%
PUGET SOUND COATINGS	15	39,773	113	0.0%
DUWAMISH SHIPYARD INC.	15	27,124	107	0.0%
DYNO BATTERY INC	5	67	91.4	0.0%
LAFARGE NORTH AMERICA	15	84	73.4	0.0%
INDUSTRIAL PLATING CORP	13	470	73.0	0.0%
ASH GROVE CEMENT CO	13	62	55.9	0.0%
EQUILON ENTERPRISES LLC SEATTLE LUBRICANTS PLANT	3	500	39.2	0.0%
FORMULA CORP	15	750	25.9	0.0%
DARIGOLD-RAINIER	13	1755	17.0	0.0%
TRIM SYSTEMS	15	7951	9.4	0.0%
PROLIANCE INTERNATIONAL INC	15	1	0.18	0.0%
HUSSMANN CORP.	15	1830	0.00	0.0%
Total of all facilities (n = 26)		275,797	905,345	
2009				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
SOUND PROPELLER SERVICES SOUTH PARK	15	20	26,871	76.9%
EQUILON ENTERPRISES LLC	3	4000	3620	10.4%
BP WEST COAST PRODUCTS CO - SEATTLE TERMINAL	3	4551	1299	3.7%
SAINT-GOBAIN CONTAINERS INC	15	383	792	2.3%
BOEING COMMERCIAL AIRPLANE GROUP NORTH BOEING FIELD	15	7600	694	2.0%
PUGET SOUND COATINGS	15	36,931	500	1.4%
NUCOR STEEL SEATTLE INC	3	1438	496	1.4%
RUDD CO INC	3	5615	196	0.6%
ASH GROVE CEMENT CO	13	135	111	0.3%
LAFARGE NORTH AMERICA	15	43	79.3	0.2%
NON-FERROUS METALS INC	15	31	77.7	0.2%
VIOX CORP	15	19	67.3	0.2%
MOREL INDUSTRIES	15	250	67.1	0.2%
BOEING COMMERCIAL AIRPLANE GROUP PLANT 2	15	2018	65. 8	0.2%
CERTAINTEED GYPSUM SEATTLE	15	1	1.32	0.0%
ASKO PROCESSING INC	5	10	0.83	0.0%
DARIGOLD - RAINIER	13	10	0.65	0.0%
SCHIPPERS & CREW INC	2	0	0.44	0.0%
VISTA-PRO AUTOMOTIVE LLC	15	0	0.41	0.0%
Total of all facilities (n = 19)		63,055	34,944	

Table S2. *Cont.*

1990–2009				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
PSF INDUSTRIES INC.	13	15,864	35,725,552	50.7%
AMERICAN TAR CO.	5	1255	11,670,515	16.5%
ALASKAN COPPER WORKS	13	1570	6,521,082	9.2%
SOUND PROPELLER SERVICES LAKE UNION	5	3282	4,981,110	7.1%
BOEING COMMERCIAL AIRPLANE GROUP PLANT 2	15	2,165,994	2,966,925	4.2%
SOUND PROPELLER SERVICES SOUTH PARK	15	1540	2,843,362	4.0%
SEATTLE STEEL INC.	3	44,100	1,395,724	2.0%
WESTERN STEEL CASTING CO.	13	9000	1,062,167	1.5%
WESCOR GRAPHICS CORP.	9	175,830	624,489	0.9%
ASKO PROCESSING INC	5	212,114	508,357	0.7%
ART BRASS PLATING INC.	15	316,631	364,698	0.5%
NORTHWEST CASTINGS	13	3994	308,478	0.4%
NORTH STAR CASTEEL PRODUCTS INC	13	8260	275,299	0.4%
PRECISION ENGINEERING INC.	15	250	211,857	0.3%
DIETZGEN CORP.	13	4825	147,833	0.2%
INDUSTRIAL PLATING CORP	13	86,958	106,003	0.2%
ASH GROVE CEMENT CO	13	1132	98,951	0.1%
NORTHWEST PLATING CO.	13	69,949	89,171	0.1%
SAINT-GOBAIN CONTAINERS INC	15	3731	88,130	0.1%
ASKO PROCESSING INC. COLOR TECH. DIV.	3	112,684	87,705	0.1%
NUCOR STEEL SEATTLE INC	3	289,471	86,781	0.1%
PACIFIC SOUND RESOURCES	3	447,203	71,467	0.1%
CAPITAL INDUSTRIES INC	15	480,784	42,271	0.1%
ROMAC INDUSTRIES INC.	15	58	42,081	0.1%
A. O. SMITH WATER PRODUCTS CO.	13	126,000	34,799	0.0%
EQUILON SEATTLE TERMINAL	3	45,829	34,482	0.0%
TRIM SYSTEMS	15	167,419	33,918	0.0%
FABRICATED PRODS. INC. (DBA SEAFAB METALS CO.)	3	6576	16,883	0.0%
BP WEST COAST PRODUCTS CO—SEATTLE TERMINAL	3	51,674	16,634	0.0%
RUDD CO INC	3	211,725	15,364	0.0%
VIOX CORP.	15	3660	11,540	0.0%
TODD PACIFIC SHIPYARD CORP	3	564,060	11,209	0.0%
BOEING COMMERCIAL AIRPLANE GROUP NORTH BOEING FIELD	15	919,419	11,077	0.0%
ACETANK & EQUIPMENT CO.	13	100,485	4498	0.0%
PUGET SOUND COATINGS	15	623,978	2649	0.0%
NON-FERROUS METALS INC	15	1100	2571	0.0%
HARSCO CO HECKETT MULTISERV PLANT 65	3	179	2268	0.0%
LAFARGE NA	15	1036	2181	0.0%
DYNO BATTERY INC	5	1184	1768	0.0%
BALLARD BRASS & ALUMINUM	3	3500	1596	0.0%
DARIGOLD - RAINIER	13	121,538	1135	0.0%
DUWAMISH SHIPYARD INC.	15	153,952	737	0.0%

Table S2. *Cont.*

1990–2009				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
EQUILON ENTERPRISES LLC SEATTLE LUBRICANTS PLANT	3	3852	677	0.0%
SCOTT GALVANIZING CO INC	2	599	612	0.0%
VISTA-PRO AUTOMOTIVE LLC	15	68	315	0.0%
FORMULA CORP	15	8760	295	0.0%
PROLER RECYCLING INC.	15	39,201	217	0.0%
LAKE UNION DRYDOCK CO.	5	12,000	134	0.0%
MOREL INDUSTRIES	15	500	133	0.0%
STROH BREWERY CO. RAINIER BREWERY	13	20,030	133	0.0%
WESMAR CO. INC.	3	1250	80.2	0.0%
KELLY-MOORE PAINT CO	13	18,993	79.3	0.0%
NORTH COAST CHEMICAL CO. INC.	15	0	53.4	0.0%
FURON CO. AEROSPACE COMPONENTS DIV.	13	28	45.9	0.0%
AVTECH CORP	5	24,877	45.5	0.0%
YOUNG CORP.	13	8170	43.8	0.0%
PROLIANCE INTERNATIONAL INC	15	179	32.1	0.0%
CONTOUR LAMINATES LP	15	23,111	15.3	0.0%
GM NAMEPLATE INC	5	64,850	12.8	0.0%
SCHIPPERS & CREW INC	2	4	11.1	0.0%
HUSSMANN CORP.	15	25,525	9.17	0.0%
BARDAHL MANUFACTURING CORP	3	0	5.51	0.0%
CERTAINTEED GYPSUM SEATTLE	15	2	5.39	0.0%
SKILLS INC.	3	43,250	4.90	0.0%
MAMCO MANUFACTURING INC.	3	15,387	3.10	0.0%
ASAHIPEN AMERICA INC	3	2520	3.08	0.0%
US COAST GUARD BASE SEATTLE	15	0	2.35	0.0%
MARCO SEATTLE SHIPYARD	5	7950	1.62	0.0%
KORRY ELECTRONICS CO.	5	10,090	1.41	0.0%
CZS ENT (DBA COWMAN CAMPBELL PAINT CO)	2	255	0.53	0.0%
SKYLINE ELECTRIC & MFG. CO.	13	2230	0.29	0.0%
FLINT INK CORP.	15	189	0.22	0.0%
SEATTLE BIODIESEL LLC	15	1010	0.13	0.0%
BURLINGTON ENVIRONMENTAL INC.	15	5	0.07	0.0%
GREAT WESTERN CHEMICAL CO. SEATTLE BRANCH	15	500	0.07	0.0%
GE CO AIRCRAFT ENGINES	15	61	0.01	0.0%
ABC METAL FINISHING INC.	15	0	0.00	0.0%
ACE GALVANIZING INC.	5	0	0.00	0.0%
ARCTIC ICE CREAM NOVELTIES	13	0	0.00	0.0%
AVTECH CORP	5	0	0.00	0.0%
BAYER HEALTHCARE LLC	2	5	0.00	0.0%
BIRD-JOHNSON CO. BALLARD	3	0	0.00	0.0%
BOC GROUP INC AIRCO GASES DIV.	15	0	0.00	0.0%
BOTTLING GROUP L.L.C.	13	0	0.00	0.0%

Table S2. *Cont.*

1990–2009				
Facility	**Cluster**	**Pounds**	**Risk Value**	**Total Risk, %**
CASCADE COLUMBIA DISTRIBUTION	5	0	0.00	0.0%
CASCADE COLUMBIA DISTRIBUTION	15	0	0.00	0.0%
CHEMITHON CORP.	15	0	0.00	0.0%
FENTRON BUILDING PRODUCTS CO	2	0	0.00	0.0%
GLACIER NORTHWEST INC EAST MARGINAL WAY PLANT	15	0	0.00	0.0%
GLACIER NORTHWEST INC. WEST MARGINAL WAY PLANT	15	0	0.00	0.0%
INGERSOLL-RAND CO. BEEBE MATERIAL HANDLING	13	0	0.00	0.0%
LOCKHEED SHIPBUILDING CO.	13	0	0.00	0.0%
NORTHWEST BUILDING TECH	15	0	0.00	0.0%
PENDLETON FLOUR MILLS LLC	3	0	0.00	0.0%
ROGERS OLYMPIC CORP.	13	0	0.00	0.0%
RUDD CO. INC.	3	168,985	0.00	0.0%
SEATTLE POTTERY SUPPLY INC	15	0	0.00	0.0%
SEATTLE TECHNICAL FINISHING INC	14	0	0.00	0.0%
SKILLS INC.	5	0	0.00	0.0%
UNITED MARINE INTERNATIONAL	5	0	0.00	0.0%
UNITED MARINE INTERNATIONAL	15	0	0.00	0.0%
YOUNG CORP. MELTEC DIV.	3	0	0.00	0.0%
Total of all facilities (n = 102)		8,064,229	70,528,319	

Just two facilities in 1990 therefore accounted for 87.25 percent of the city's overall relative-risk from air pollution exposure. In third place, and accounting for just 5.7 percent of the air pollution relative-risk was Boeing Commercial Airplane's Plant number 2 located in the southern most reach of the GDMIC industrial area in Cluster 15. Seattle Steel followed closely behind in fourth place and is located in the northwestern corner of GDMIC. Of the remaining six TRIs in the top ten in bold lettering, only one (Asko Processing) was located in BINMIC.

In the 2000 rankings, PSF industries and American Tar fell off the top ten list. According to the State of Washington's Department of Ecology (WADOE), the American Tar company manufactured roofing products and formulated wood preservatives but ceased operations in 1991. A developer then bought the property, WADOE invested $1.5 million for the site cleanup, and a contractor finished in under six months [54]. PSF industries reported air toxics emissions from fugitive sources until 1994 according to the EPA's Toxics Release Inventory (TRI) Explorer database and ceased reporting but still operates at the GDMIC location in Cluster 13 [55]. At the top of Seattle's 2000 relative-risk rankings, Sound Propeller Services on the east side of Lake Union and in Cluster 5 accounted for 70.26 percent of the city's simulated industrial air pollution inhalation exposure risk. Alaskan Copper Works in Cluster 13 and Wescor Graphics and Art Brass Plating in Cluster 15 were a distant second, third and fourth in the pollution ranking with 9.6, 7.1, and 5.2 percent of relative air toxic risk respectively. The remaining 22 facilities in the 2000 list contributed very little to the relative-risk levels of Seattle's air pollution riskscape.

By 2009, Sound Propeller Services had relocated from Cluster 5 to Cluster 15 and again ranked as Seattle's worst polluter while reporting only 20 pounds of air emissions. They produced 76.9 percent of the city's air toxic relative-risk exposure because they were reporting fugitive chromium and nickel compound emissions that pose much higher inhalation risks than other toxic release even at higher levels [56]. They also were located in closer proximity to residential homes than in their Lake Union location. Two facilities in Cluster 3 (Equilon Enterprises and Saint-Gobain Containers) again ranked a distant second and third accounting for 10.4 and 3.7 percent of Seattle's air toxic risk from industrial polluters. The North Boeing Field facility ranked fourth with 2 percent of the city's relative air pollution risk while Nucor Steel in Cluster 3 and Puget Sound Coatings in Cluster 15 tied for fifth place. Another 12 facilities produced less than 2 percent of Seattle's air toxic risk. By the end of our RSEI dataset study period, air pollution volumes had dropped dramatically from over 2 million pounds to less than seventy-thousand pounds in 2009; a decline of ninety-seven percent. The relative-risk scores also plunged from over 30 million to less than forty thousand in 2009.

Table S2 also provides an accounting of the uneven clustering of Seattle's environmental inequality over two decades. Between 1990 and 2009, six facilities were responsible for over ninety percent of Seattle's simulated inhalation risk exposures from air pollution. American Tar was present just north of Lake Union between the BINMIC and SLU industrial areas in Cluster 5 with another on the lake's eastern edge. Sound Propeller moved from Cluster 5 to Cluster 15 in the GDMIC industrial area in 2005 and joined four other facilities in South Seattle's Manufacturing zone by the end of our study period. In 1990, GDMIC facilities represented 8 of the ten riskiest facilities across the city's riskscape. In 2000, the riskscape was more evenly distributed with three of the riskiest air polluters scattered around Lake Union north of downtown and BINMIC hosting one of the largest air polluters by volume. The Rudd paint and coating facility reported releases of over thirty-one thousand pounds of toxic pollution emissions [56]. By 2009, this facility was the only site outside of the GDMIC industrial area making the list of the ten riskiest polluters.

4. Industrial Land Use Trajectories

Figure S1 maps the urban village development areas from Seattle's 1994 plan. Across North Seattle, five Hub Urban Villages (HUV) were designated including at the northern end of Aurora Avenue on the northwest edge of the city and in Lake City near the northeast edge of the city. Two more were on the northwest and northeast corners of the BINMIC industrial area in Ballard and Fremont. The fifth HUV encompassed the industrial zone on the southern tip of Lake Union. In South Seattle, two HUVS were designated as the West Seattle Junction and Rainier Avenue at Interstate 90. Moreover, these designations were in close proximity to four of Seattle's riskiest air toxic inhalation exposure sources in the 2000 riskscape.

In the BINMIC zones, 16 out of 23 non-industrial to non-industrial construction use permits were clustered at the top of BINMIC between the Ballard and Fremont Hub Urban Village northwest of Lake Union (see Figure S2). Only three new industrial sites were located in BINMIC while 20 appeared in GDMIC. Moreover, five were in close proximity to the Georgetown and Southpark residential neighbourhoods. The distribution of GDMIC land use permits also has a clustering pattern with more commercial activity on the Northside including a cluster near the southeast urban hub

village (see Figure S3). Eight industrial land use change permit sites are located near the Georgetown and Southpark communities while none appear near the SLU urban village. This despite a more recent update of the comprehensive plan stating the goal to: "Preserve industrial land for industrial uses and protect viable marine and rail-related industries from competing with nonindustrial uses for scarce industrial land" [57]. Nonetheless, 15 blocks of industrial zoned land in the SLU neighbourhood were rezoned in 2007 to "Seattle Mixed" which combines residential and commercial uses. In short, city policies and permitting displayed a pattern of abandoning industrial activity in SLU, slowing in BINMIC, but expanding in GDMIC.

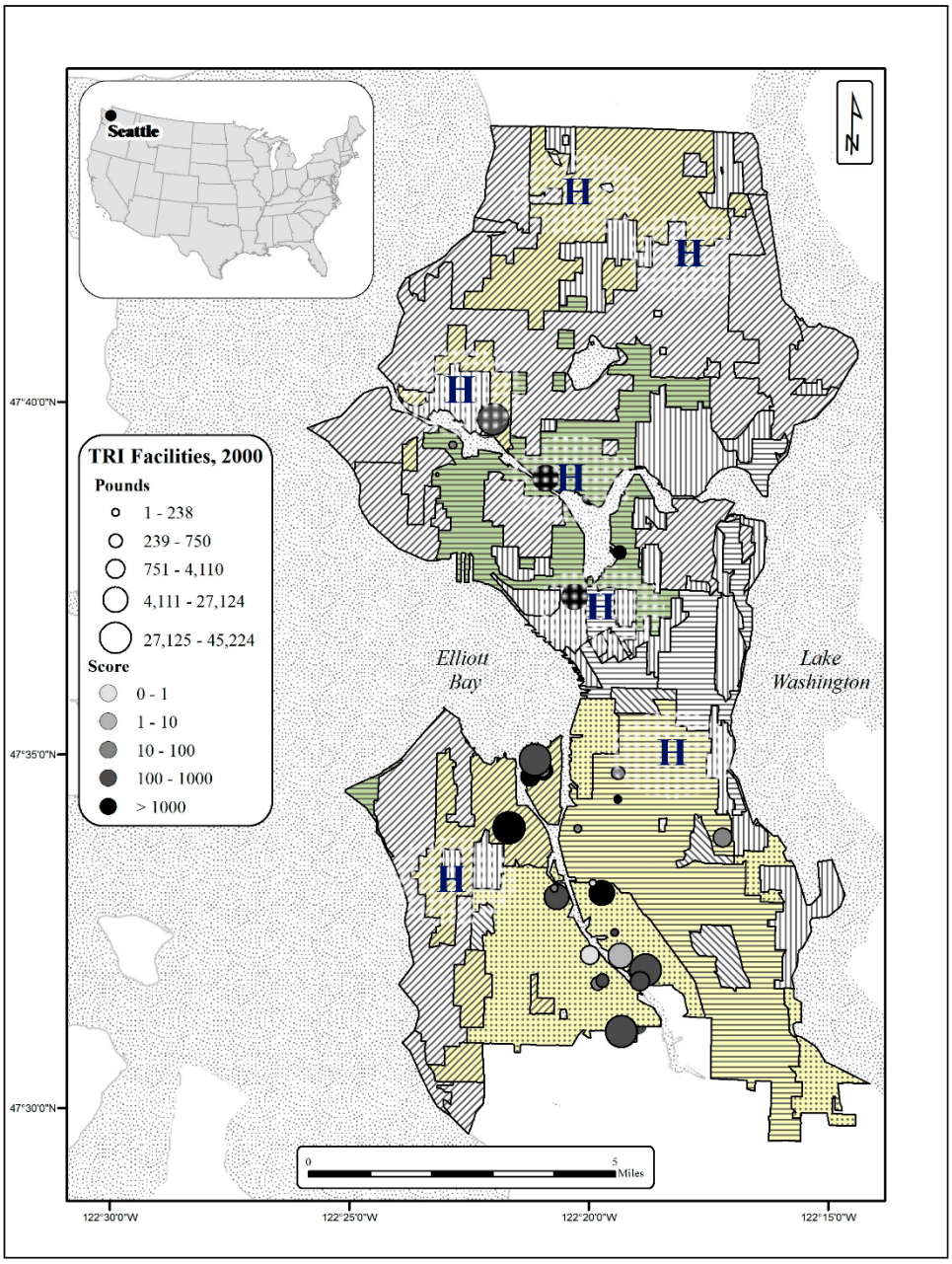
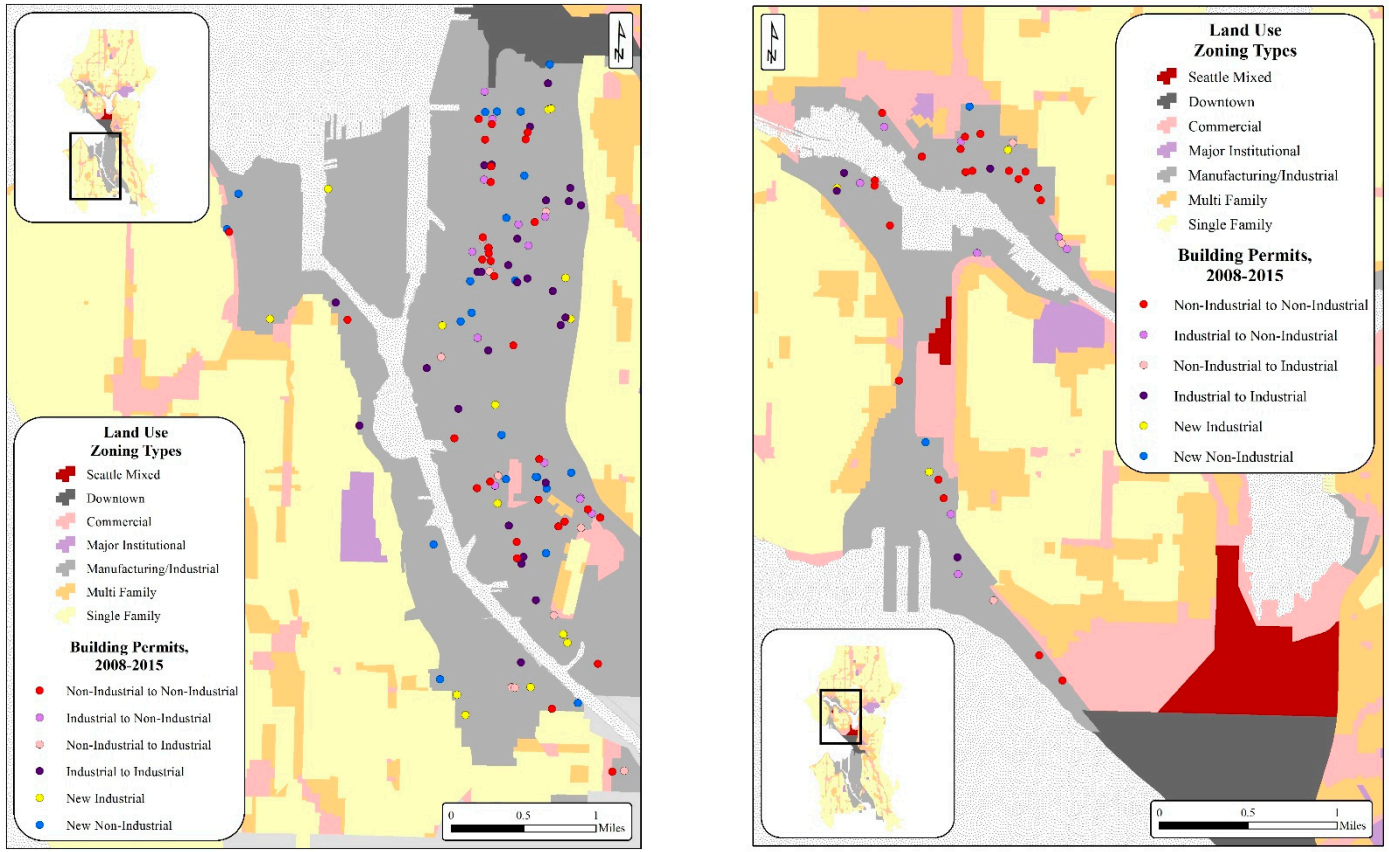
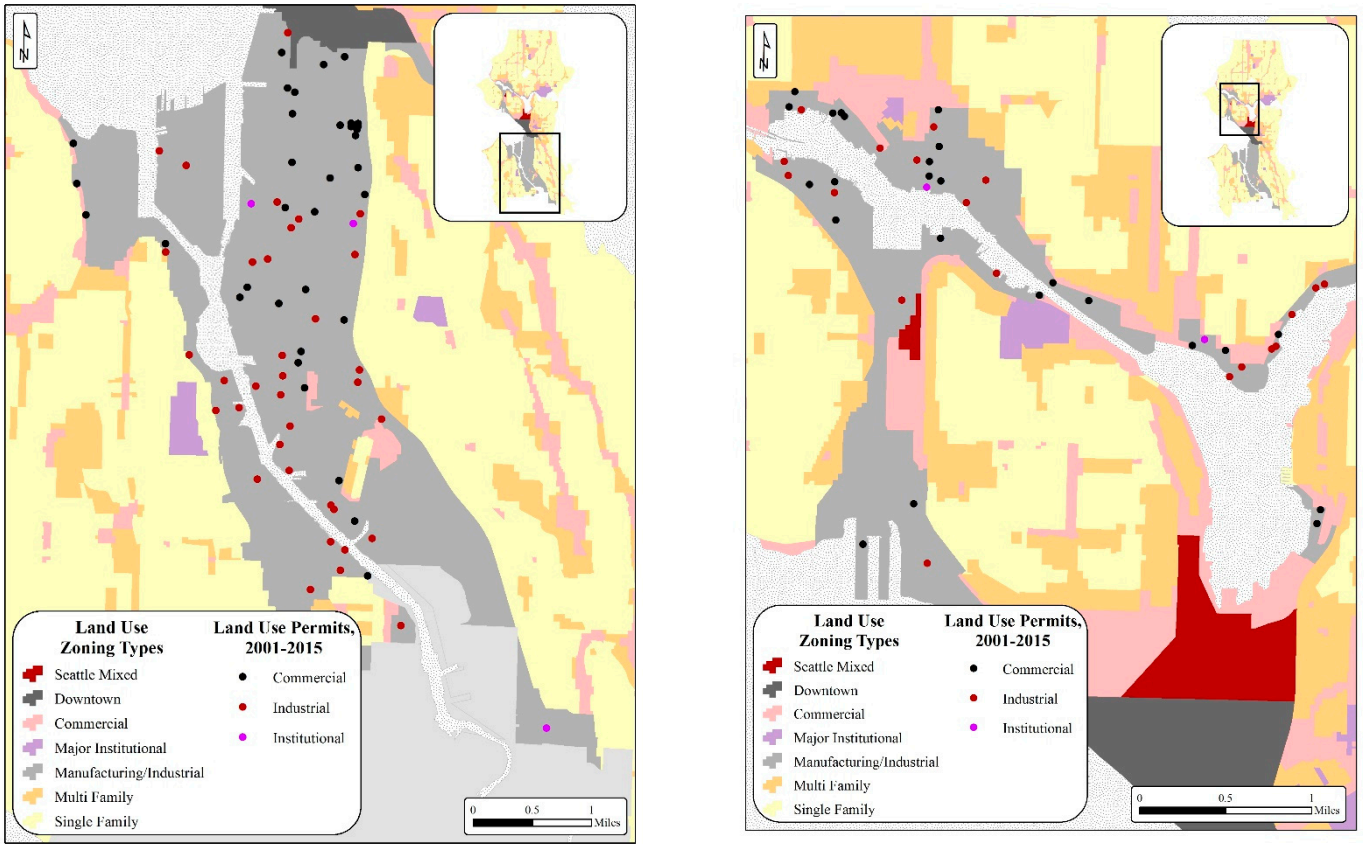


Figure S1. Seattle's hub urban village land use (H) Designations in 1994 and the 2000 industrial air toxic inhalation exposure riskscape.



(**a**) (**b**)

Figure S2. (**a**) GDMIC construction change of use permits issued, 2008–2015 [58] and (**b**) BINMIC [59].



(**a**) (**b**)

Figure S3. (**a**) GDMIC land use permits issues, 2001–2015 [60] and (**b**) BINMIC [61].

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Author Contributions

Troy D. Abel originated the study, prepared the relative risk screening exposure modeling, conducted the qualitative analysis, and led the writing of the article. Jonah White designed and conducted the factor and cluster analysis and contributed to the writing of the article. Stacy Clauson collected health and air monitoring data and contributed to the writing of the article.

Conflicts of Interest

The authors declare no conflict of interest.

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58. Between 2008 and 2015, a total of 153 building permits were issued in GDMIC: 35 for Non-industrial to Non-industrial (23%); 20 for Industrial to Non-industrial (12%); 14 for Non-industrial to Industrial (9%); 39 for Industrial to Industrial (26%); 20 for new Industrial (13%); and 25 for new Non-industrial.
59. Between 2008 and 2015, a total of 50 building permits were issued in BINMIC: 23 for Non-industrial to Non-industrial (46%); 12 for Industrial to Non-industrial (20%); 5 for Industrial to Industrial (10%); 3 for new Industrial (6%); and 2 for new Non-industrial (4%).
60. Between 2001 and 2015, a total of 81 land use permits were issued in GDMIC: 35 for Commercial (43%); 42 for Industrial (52%); and 4 for Institutional (5%).
61. Between 2001 and 2015, a total of 49 land use permits were issued in BINMIC: 25 for Commercial (51%), 20 for Industrial (41%), and 3 for Institutional (6%).

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