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Blurred Vision? Evaluating the Legacy of Puget Sound Smart Growth

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Blurred Vision?
Evaluating the Legacy of Puget Sound Smart Growth

By
Stacy Clauson

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

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Date: November 10, 2016
Blurred Vision?
Evaluating the Legacy of Puget Sound Smart Growth

A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Completion
Of the Requirements for the Degree
Master of Science

By
Stacy Clauson
Abstract

This research examines tensions in Smart Growth in Central Puget Sound, Washington, an early adopter of regional planning influenced by Smart Growth planning principles. I examine evidence of social equity, environmental exposure, and health outcomes. Using longitudinal geographic cluster analysis, longitudinal and cumulative air pollution analysis, and health assessment, I compare socioeconomic changes with environmental and health measures. My research indicates that economic inequality has increased over time and the region remains spatially divided by socioeconomic status and race and ethnicity, despite implementation of Smart Growth policies that were intended to improve social equity outcomes. Further, despite a trend of de-industrialization that has occurred within the region over time, air pollution risks have remained skewed and have spatially concentrated, with the adverse impacts of exposure falling disproportionately on struggling communities within the region. Exposure to cumulative air pollution risks remains high in areas targeted for more compact development. Finally, my research reveals that air pollution related health outcomes are worsening, and are associated with lower socioeconomic status and higher exposure, both of which are influenced by place. These results raise critical issues about the Central Puget Sound's Smart Growth planning efforts. Further, it reveals ways in which Smart Growth is falling short of meeting the visionary goal to transform our cities and regions into more equitable places.
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Chapter 1. The Limits of Smart Growth?

The places created and managed by different private and state actors play an important role in shaping social, economic and health outcomes. The strategies and tools of urban planning "...are some of the most explicitly spatial forms of state attempts to manage social and economic relations" (Huxley 2008, p. 123). As a result, it is paramount that practitioners, policymakers and citizens understand the implications of planning decisions. Yet, there is a long history of critical urban studies that raise problems with the effectiveness of planning strategies and tools, particularly with respect to equity outcomes (Harvey 1996; Huxley 2008; Wilson et al 2008). Planning, in these critiques, is limited in its ability to effect change. As noted by Huxley (2008), "...either it has no effects other than to support the status quo or if it has any effects, they are largely negative, exacerbating existing inequalities" (p. 126). Thus, there exists a theoretical divide that separates scholars based on their interpretation of the effectiveness of planning in addressing issues of equity; on one end of this spectrum are scholars that believe planning decisions make a difference for the better, while on the other end are scholars that believe planning decisions result in largely negative effects, further adversely impacting equity outcomes. In the middle are those that view planning are having limited ability to effect change.

I engage in this study to evaluate the equity outcomes of Smart Growth, a planning framework that has emerged as a countermeasure to sprawl and has been theorized to benefit all citizens, regardless of class or race, by improving livability and built environment conditions. My research, which focuses on the Central Puget Sound region, assesses whether the strategies and tools of Smart Growth produce better or worse equity outcomes for different groups, or whether they make a difference at all. The Central Puget Sound region (also known as Greater
Seattle) has a reputation as a thriving region that has transformed itself from a 20th century natural resource economy, to a new economy powerhouse, with successful high technology and trade centered companies. Richard Morrill, a well-known Geography scholar, once remarked, "It is often held up as one of the role models…, so its experiences should be considered seriously" (Morrill 2009, n.p.). The region is known for its prosperity and livability, and Benner and Pastor (2015) have heralded it as an example of a region making strides to ensure that the benefits of its economic growth are distributed equitably¹. My findings, in contrast, reveal problems with the region's Smart Growth planning on several fronts, including social equity, environmental and health outcomes.

Why does place matter? Where a person lives affects their opportunities and contributes substantially to their lived experience, both positively and negatively. The spatial arrangement of our communities therefore has a profound effect on how we participate in urban life and whether we are able to use and shape where we live as an equal, what Lefebvre (1996) refers to as the 'Right to the City'. As noted by Chapple (2014),

Neighborhoods can affect economic outcomes through several different mechanisms. They may shape what school a child attends and what other social institutions are available for assistance. They shape access to amenities and resources such as parks and jobs. They can affect the extent and type of contacts in a social network. And, at the most basic level, they determine exposure to hazards such as toxics and crime (p. 270). Presently, a number of inequalities permeate our spaces, ranging from income to environmental inequality. Historical housing and land use practices such as restrictive covenants, red-lining, urban renewal, suburbanization and exclusionary zoning have resulted in housing segregation, reduced opportunity, and in many cases elevated environmental and health risks to economically

¹ Benner and Pastor (2015) found that the region had positive growth and equity trajectories over the 30-
disadvantaged communities and communities of color. While many of these intentionally discriminatory practices have since been eliminated, they continue to shape the landscape of our metropolitan regions.

What are the possibilities of planning? As remarked by Molotch (1993), Lefebvre's writings on the production of space present a call to action, "To save the earth as well as enhance the lives of those within it, a praxis is needed that sees through the mystifications of past space productions and that consciously and deliberatively strives to create new spaces" (p. 891). Planning, with its ability to remake space through varied tools such as zoning and development control, redevelopment, grants, and incentives, seemingly has the potential to fulfill this role, to remake spaces that are more equitable (Huxley 2008). "The managers of the urban system exert an independent influence on the allocation of scarce resources and facilities which may reinforce, reflect or reduce the inequalities…” (Pahl 1974 as quoted in Williams 1978, p. 236). From this perspective, planning is a tool that can be used to remake space and impact inequalities, either positively or negatively.

There are varying perspectives about the appropriate role of planning in improving equity outcomes. For example, there is a growing movement for planners to participate in 'equity planning' (Metzger 1996; Krumholz 2011), in which planners use their role in the policymaking process to encourage and facilitate redistributive programs and policies. In contrast, scholars from the communicative model of planning, which re-orient planning from a rational to a collaborative planning approach that emphasizes participatory planning and inclusionary decision-making, focus on creating a more open and democratic practice to produce year time period for their analysis (1980 – 2010).
just results (Healey 1999; Fainstein 2010). Scholars advocating for regionalism incorporate this concept into regional planning processes, focusing on facilitating communication amongst diverse communities to address regional challenges and improve equity outcomes (Pastor and Benner 2015). Smart Growth initiatives, which focus growth into compact, mixed-use urban areas that are served by a variety of transportation options, has emerged as an alternative to sprawl and has been theorized to produce improved equity outcomes (Ewing and Hamidi 2015). Through these different planning approaches, local and regional political bodies, exercising their planning authority, have the power to "...mediate [the relations between spaces, environments, and citizens] in particular ways in particular places to bring about meaningful improvements" (Huxley 2008, p. 127).

Counter to these views, a number of different theoretical perspectives have expressed that planning is ineffectual and limited in its ability to bring about changes in equity outcomes (Huxley 2008). From this perspective, "Planning is always ultimately constrained to operate in accordance with dominant power relations, and thus is largely discounted as having a positive part to play in transforming the spatial relations between states and citizens" (Huxley 2008, p. 130). Again, there are varying perspectives as to why planning is unable to improve equity outcomes traditions (e.g., neo-Marxian, feminist, and regulation theory). From one perspective, planning is viewed as supporting capitalist accumulation, and therefore has limited ability to manage the processes leading to existing inequalities. For example, Harvey (1985, 1996) is critical of what he perceives to be planning's fixation with the spatial form and the built environment, which obscures the underlying structural processes that contribute to inequality; without the ability to engage with these processes, planning is unable to bring about change. From the perspective of feminist studies, planning "...inevitably serves to perpetuate the
patriarchal nature of spatial arrangements” (Huxley 2008, p. 130). Despite differences conceptualizations of the dominant power (e.g., capitalism or patriarchy), these perspectives are unified in their belief that planning, in its current form, is incapable of addressing the processes leading to inequality.

Finally, a third perspective holds that planning exacerbates existing inequalities. As explored by Huxley (2008), this viewpoint comes from neo-liberals concerned with the overreach of planning. As stated by Huxley (2008),

…planning’s attempts to reform spaces and places, and regulate the production of the built environment, are doomed to failure, not only because they interfere with the operations of the market, but also because no one bureaucrat or organization can possibly have enough knowledge to plan for all eventualities and forestall all intended consequences” (p. 130).

Social and economic forces, rather than the state, are viewed as having the potential to bring about better outcomes.

Concerns remain that many of the contemporary strategies used by communities to control sprawl and revitalize communities, such as brownfield redevelopment, transit-oriented development, and commercial corridor redevelopment, have the potential to perpetuate development inequality. Community activists and urban planning scholars have raised concerns that these strategies lack focus on social equity and justice principles and have priced disadvantaged communities out of revitalized neighborhoods. As a result, disadvantaged communities are not able to participate in the new opportunities that urban revitalization provides (Chapple 2014; Wilson et. al 2008). Further, the processes of displacement, gentrification and exclusion have been heightened with the 'Back to the City' movement that has resulted in a resurgence of growth and redevelopment within core areas of cities. Thus,
ironically the 'Back to the City' is viewed as depriving economically disadvantaged communities their 'Right to the City'.

1.1. Purpose of Research

In this study, I engage in this ongoing debate about the outcomes of Smart Growth planning, using the Central Puget Sound region as a case study. I examine whether Smart Growth focused policies result in equitable development or, conversely, replicate the type of inequitable development processes that brought about the movement for environmental justice. My analysis incorporates methods from the study of neighborhood change to explore the evolution of the demographic and socioeconomic fabric of the Central Puget Sound region. I also examine the changing pollution landscape, using a variety of data sources and methods to examine both the distribution of pollution sources as well as exposure to poor air quality for different social groups over time. Finally, I explore the linkages among the region's social equity, air pollution riskscape, and health outcomes.

I pull from different theoretical and empirical traditions to address gaps in current data and research addressing equitable development and environmental inequality formation, which are both focused on the outcomes of policy decisions and whether the benefits and costs are equitably distributed. First, my analysis examines change over a long time period, from 1990 to 2014. Studies incorporating this type of longitudinal analysis have been few (see Stroud 1999; Pulido 2000; and Szaz and Meuser 2000, as examples), but have shed light on historically embedded processes that are important to understanding environmental inequality formation (Walker 2012; Mohai and Saha 2015). Moreover, my study analyzes health outcomes and explores the relationship between health outcomes and socioeconomic and exposure factors. This step fills a key gap identified by Buzzelli (2007, as referenced by Walker 2012), of
"...probing the linkages' between unequal distributions and health consequences [as] the necessary next step towards a 'new framework' for environmental justice research" (p. 116). In addition, I examine multiple pollution sources to ascertain a more complete understanding of cumulative exposure. Finally, my research responds to Dwyer's (2010) call for research into regional policies, including anti-sprawl policies like Smart Growth, to determine how these initiatives affect residential segregation. I analyze policy outcomes from Smart Growth planning implementation, adding new empirical information and methods to the growing body of literature that critically examines equitable development and local and regional planning efforts (e.g., Abel and White 2015; Abel et al. 2015; Chapple 2014; Goodling et al. 2015).

1.2. Research Questions

This research is guided by three primary objectives: 1) to examine the socio-spatial outcomes of the Central Puget Sound's regional growth planning efforts; 2) to identify whether skewed environmental riskscapes have formed in the Central Puget Sound region; and 3) to explore the linkages among socioeconomic status, air pollution riskscapes, and health outcomes within the region. In this context, riskscapes refer to the spatial variation in environmental risks and potential vulnerability to environmental hazards. As a way to examine the complexities of Smart Growth implementation and its social, environmental, and health equity outcomes, I focus on three inter-related research questions:

(1) How have the region's socioeconomic outcomes changed over time?
(2) Do the location, distribution and intensity of environmental hazards in the region result in skewed riskscapes, in which some neighborhoods face disproportionally higher risks?
What linkages exist among the socioeconomic status, air pollution distribution, and health outcomes?

My research indicates that economic inequality has increased over time and the region is more spatially divided by socioeconomic status and race and ethnicity, despite implementation of Smart Growth policies that were intended to improve social equity. This finding is consistent with Dierwechter (2014), in his analysis of Puget Sound Smart Growth. Further, despite a trend of de-industrialization that has occurred within the region over time, air pollution risks have remained skewed and have spatially concentrated. These findings are also consistent with a number of published air quality studies that show higher pollution concentrations and potential risks in the Duwamish Valley area of south Seattle (PSCAA 2010; Wu et al 2011; Schulte et al 2013, 2015). The adverse impacts of exposure, in turn, fall disproportionately on economically disadvantaged communities and communities of color within the region.

These findings are consistent with a series of published studies by Abel and White (2011, 2015) evaluating Seattle’s pollution riskscape. Their findings were that Seattle’s “pollution riskscape and urban development burdens were skewed toward the city’s most socially vulnerable residents” (Abel and White 2011, p. 252). Scaled up the region, these findings still hold true. Finally, my research reveals that air pollution related health outcomes are worsening, and are associated with lower socioeconomic status and higher exposure, both of which are influenced by place. These results raise critical issues about the Central Puget Sound’s Smart Growth planning efforts under the Vision 2040 regional plan. Further, my study reveals ways in which Smart Growth is falling short of meeting the visionary goal to transform our cities and regions into more equitable places.
1.3. Organization of Thesis

The remainder of this thesis is organized into five chapters. Chapter 2 details the theoretical literature that informs this study. I triangulate scholarship on equitable development, environmental inequality formation, and social determinants of health to inform my analysis. I also provide background on the regional growth planning efforts in the Central Puget Sound. Chapter 3 details the research approach, data, and methods that guided my research. I combine different empirical approaches. For the analysis of social equity, I create neighborhood typologies and analyze trajectories of neighborhood change over time. To assess skewed riskscapes, I analyze industrial point source pollution and exposure data over time, identify hotspots of concentrated exposure risk, and explore the relationship between exposure and socioeconomic characteristics. To analyze health outcomes, I examine asthma-related hospitalization over time and conduct correlation analysis to explore the relationship between the region's socioeconomics, air pollution distribution, and health outcomes. Chapter 4 presents results of these different analyses. The first section focuses on the region's socioeconomic equality outcomes. The second section addresses the air pollution riskscape, while the third section contains information on the analysis of health outcomes. Chapter 5 analyzes the key claims about social equity, air pollution exposure and health outcomes associated with the Smart Growth strategy incorporated into Vision 2040, incorporating the results from Chapter 4. In Chapter 6, I summarize my research findings and outline the limitations of my study and areas of future work.
Chapter 2. Background

My research triangulates among three theoretical traditions: equitable development, environmental inequality formation and social determinants of health. In the following section, I first introduce the concept of equitable development and its connections to Smart Growth, concluding with an overview of the tensions that exist in Smart Growth scholarship. Next, I examine the theory of environmental inequality formation. I review the development of the theory as well and its connections to Smart Growth. I then summarize research into social determinants of health and health inequities, including efforts to reconnect community and regional planning to public health in order to address health disparities. Finally, I provide an overview of regional planning in the Central Puget Sound region, the focus of this case study.

2.1. Equitable Regional Planning and Development

Equitable development, as defined by the US Environmental Protection Agency (US EPA 2016a),

… draws on both environmental justice and smart growth and generally refers to a range of approaches for creating communities and regions where residents of all incomes, races, and ethnicities participate in and benefit from decisions that shape the places where they live.

Equitable development is focused on fostering positive outcomes that provide everyone the capacity and opportunity needed to thrive. Equitable development has emerged in planning literature (Chapple 2014; Blackwell 2000; Blackwell and Bell 2005) as well as in a number of toolkits designed for planning practitioners (McConville 2013; PolicyLink 2016; Center for Housing Policy 2011). As noted by Angela Glover Blackwell, the president and founder of
PolicyLink, equitable development requires “...the promotion and management of economic growth that maximizes benefits for residents of low-income communities throughout metropolitan regions and assures their voice in the development process” (Blackwell 2000, p. 1283). At a broad level, equitable development is based upon three key interrelated concepts: 1) meaningful community engagement, 2) investment in existing communities, and 3) improving access to opportunity. My research most closely engages with concepts 2 and 3, which I now focus on.

In order to promote equitable development, planners and policymakers have invoked a number of different policy tools. For example, a variety of placed-based approaches to encourage revitalization have been designed to facilitate reinvestment within existing communities, including brownfield redevelopment, infill development of underutilized properties, and conversion of vacant or abandoned properties (McConville 2013; Chapple 2014). These strategies typically include integration of land use and transportation, with a focus on mixed-use and transit-oriented development (McConville 2013). At the same time, a number of strategies are used to improve access to opportunity. These generally fall into two different types: redistribution and encounter, as coined by Fincher and Iverson (2008).

Redistribution efforts are focused on reducing disparity between different groups by increasing diversity in communities that contain social and economic amenities, such as well performing schools and access to job opportunities. Planning techniques associated with this emphasis include a focus on density, development of mixed-income and mixed-use neighborhoods with a variety of housing types, promotion of jobs-housing balance, and

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2 PolicyLink is a national research and action institute advancing economic and social equity.
promotion of affordable and fair housing, through a variety of mechanisms (Chapple 2014; Fincher and Iverson 2008; McConville 2013). Encounter, in contrast, is focused on creating opportunities for different groups to interact (Fincher and Iverson 2008). Similar to redistribution, techniques associated with encounter include increasing diversity in communities through mixed-income communities with a variety of housing choices to meet a range of needs (Chapple 2014; Fincher and Iverson 2008; McConville 2013).

Smart Growth has been linked to the concept of equitable development (McConville 2013; Bullard 2007; Pendall et al. 2006), sharing many common themes including ensuring fair access to livelihood, health, education and resources. Smart Growth emerged in the 1990s through a series of different initiatives, including the American Planning Association (APA) (1999) Growing Smart initiative, the formation of the Smart Growth Network, led by the U.S. Environmental Protection Agency, in 1996; and the passage of Maryland's Neighborhood Conservation and Smart Growth Act in 1997 (Chapin 2012). It has become increasingly popular, with adoption of Smart Growth plans occurring over hundreds of communities (Gray, 2007; Krueger and Gibbs 2008), as well as the partnership formed between the US Department of Housing and Urban Development (HUD) the EPA, and U.S. Department of Transportation (DOT), to promote Smart Growth principles (US EPA 2016b).

While no specific definition exists (Dierwechter 2014; Gray 2007), Smart Growth is generally conceived as a set of 10 principles focused on creating and maintaining livable neighborhoods through: 1) mixing land uses, 2) using compact building design, 3) creating a range of housing opportunities and choices, 4) creating walkable neighborhoods, 5) ensuring that communities have a strong sense of place; 6) preserving open space and protecting the environment, 7) directing development towards existing communities (infill); and 8) providing
a variety of transportation options, 9) coordinating and streamlining the development approval process, and 10) encouraging community and stakeholder engagement and collaboration in policymaking (Smart Growth Network 2006; Newman 2016). Smart growth has provided a bridge to connect traditional planning adversaries, allowing planners, developers and environmentalists to come together in support of growth (Krueger and Gibbs 2008). In this vein, Smart Growth has been described by Dierwechter (2008) as comprising multiple, and conflicting, rationalities (Figure 1). Smart Growth policies attempt to work across these conflicting beliefs and achieve balance between diverging values.

Figure 1: Diagram of conflicting beliefs underlying Smart Growth (Dierwechter 2008).

Due to its increasing popularity, a number of studies of Smart Growth have been undertaken, with varying objectives. As described by Dierwechter (2013), one set of studies focuses on defining and describing Smart Growth and "debating what smart growth (might) mean and for whom" (p. 139) (Burchell et al., 2000; Downs, 2005; Song, 2012). Another line of work examines implementation and assessment of Smart Growth principles, directed at an
audience of practitioners (CA DOT 2007; Smart Growth Network 2006). Other studies have introduced critiques of Smart Growth, as part of larger efforts that question the role of planning, which is viewed as an unnecessary intrusion of the government into private property rights and market forces (Dierwechter 2013). Finally, I have also been influenced by an area of research analyzing the outcomes of Smart Growth. The conclusions from these outcomes-focused studies are varied, and have exposed certain tensions within Smart Growth research. One particular area of tension is the role of equity in Smart Growth planning, with varying conclusions on whether Smart Growth helps to ameliorate or further exacerbates inequality. My research engages in this ongoing debate, examining the social equity outcomes from the Central Puget Sound’s Smart Growth regional planning efforts.

Proponents of Smart Growth point to its role in preventing sprawl. With regards to social equity, sprawl (and the policies that support it) is a key contributor to many regional inequities, causing disinvestment in existing communities, subsidization that creates unequal economic opportunities for economically disadvantaged or communities of color, and disparate transportation funding that have shortchanged less affluent portions of metropolitan areas and created 'spatial mismatches' that limit access to jobs (Blackwell 2000; Chen 2007; Pollard 2000; Powell 2007; Orfield 1997, to name a few). In this context, sprawl is viewed as a threat to low-income families and communities of color, and threatens opportunities to achieve environmental justice. Smart Growth, in contrast to sprawl, is promoted for its potential to address income and racial segregation because of its focus on density, mixed-use neighborhoods, and urban revitalization (Bullard 2007; Pendall et al, 2005). Though environmental justice and Smart Growth movements have not typically aligned, advocates
have started to encourage collaboration in order to address the perils of sprawl (Bullard 2007; Chen 2007; Rast 2006).

Smart Growth proponents advocate that these policies provide opportunities to address historically embedded environmental, health, and economic disparities in low-income and minority communities by:

• Cleaning up contaminated sites and fostering reinvestment in existing neighborhoods, many of which have been adversely impacted by disinvestment (Pollard 2000; McConville 2013; EPA 2016a).
• Providing housing choices (e.g., mixed use zoning and variety of housing types) and reducing the exclusionary impacts of traditional single-family zoning (Arigoni 2001; Pollard 2000; Powell 2007; McConville 2013).
• Improving transportation options and enhancing mobility for communities that have been isolated by past transportation infrastructure development decisions (Chen 2007; McConville 2013; EPA 2016a).
• Reducing automobile dependency and creating development that is walkable and transit-accessible, which subsequently improves access to jobs and services, increases physical activity, and reduces automobile emissions (Chen 2007; McConville 2013; EPA 2016a).

Kushner (2002), in his assessment of Smart Growth and its impacts on poor and minority populations, acknowledges potential limitations, but nonetheless argues in support of Smart Growth, stating:

The renewed central city raises the possibility of gentrification yet offers minority and poor communities the best opportunity for enhanced access to employment, community destinations, and an improved urban living environment (p. 74).

In contrast, researchers critical of Smart Growth contend that the Smart Growth planning framework, like sustainability, does not effectively balance the competing demands of economy, environment and equity. Instead, equity considerations are overlooked. As explained by one community organizer, while Smart Growth assumes everyone is on an equal footing and interacts with the built environment in the same way, equitable development instead recognizes that people come to a place with different capacities and needs (Newman
As a result of this assumption, Smart Growth does not include sufficient people-based strategies, such as social services, retention of market-rate affordable housing, job training and local hiring within redevelopment projects and others, that would ensure that areas targeted for place-based redevelopment are also serving the needs of low-income residents to participate and benefit from this development activity. Without a more holistic strategy towards development, critics contend that infill and redevelopment associated with Smart Growth results in economically and socially divided communities, with the adverse impacts of growth and development falling on economically disadvantaged or communities of color (Kennedy and Leonard 2001). Wilson et al. (2008) claim that,

Unfortunately, the planning philosophy that drives urban revitalization focuses predominantly on urban design and aesthetics and less on social equity and justice. Thus, revitalization is expanding the pattern of inequitable development and fragmentation in metropolitan regions that occurred during the suburbanization and urban renewal eras of the twentieth century, particularly in resource-poor and segregated neighborhoods where many disadvantaged populations reside (p. 214).

As an example, some researchers have concluded that Smart Growth policies may intentionally or unintentionally limit the supply of buildable land and cause housing prices to rise (Chapple 2014; Downs 2005; Pendall et al. 2005; Pollard 2000; Pozdena 2002; Song 2012). In urban areas, these pressures are heightened as a result of the 'Back-to-the-City' movement (Chapple 2014) that is placing increasing pressure on regional core areas to accommodate a larger percentage of new residents. As land values increase as a result of increased demand, landowners begin to redevelop property to 'higher and better land uses' that maximizes return on investment (often referred to as the rent-gap theory (Smith 1979)). At the same time, high development costs associated with infill development in core areas (e.g., land acquisition, demolition and cleanup, and infrastructure and building construction) lead to increasing
housing costs (Chapple 2014). As noted by Chapple (2014, p. 68), "Because of these financial constraints, most regions with substantial infill housing development also have higher home prices".

These two processes combined (rising disparity in current versus potential income from property redevelopment and high redevelopment costs) serve to displace existing affordable housing within neighborhoods, which is then replaced by high-cost housing. Critics contend that the negative impacts of these processes fall disproportionately onto low-income and/or communities of color, which are pushed out of existing neighborhoods, disrupting social cohesion and limiting access to new amenities in redeveloped areas. "As a result, it can be argued that smart growth may not merely preserve the good life for those who already have it, but deny the good life to those who do not" (Pollard 2000, p. 284). While Smart Growth policies encourage neighborhoods to be developed with mixed uses and housing types that are intended to be more supportive of racial and economic diversity, studies indicate that the resulting infill developments are largely racially and economically homogenous (Al-Hindi 2001; Zimmerman 2001; Gordon and Richardson 1998). Smart Growth's focus on creating communities that meet the demands of middle and upper income White residents led Dierwechter (2014) to comment that Smart Growth might more correctly be called smart segregation. As noted by Chapple (2014 p. 2):

...the idea of mixing income levels in housing is core to our notions of fair housing. But given rising income inequality and segregation of the affluent, in practice it has proven ineffective at improving access to opportunity.

In addition, there has been increasing scholar attention to environmental gentrification (Abel et. al 2015; Eckerd 2011; Checker 2011), which posits that environmental cleanup attracts gentrification, resulting in the benefits of cleanup accruing to new, wealthier households who
move into an area after cleanup. In Smart Growth strategies, brownfield redevelopment is often used as a tool for revitalization and to counteract sprawl. Along the lines of environmental gentrification, many researchers studying Smart Growth have concluded that this type of redevelopment often leads to gentrification through increased property values and rents (Pearsall 2010; Pendall et al. 2005; Perkins 2007). As Rast (2006) remarks,

Aside from the obvious fairness questions it raises, gentrification is problematic from a regional reform perspective because it does not reduce inner-city poverty but simply shifts it from one location to another (p. 253).

Another critique is that Smart Growth policies have a "profound suburban, middle class bias" (Rast 2006, p. 249), focused on issues with limited social equity basis, such as protection of open space on the fringe of metro areas. It has been argued that "smart growth won't work if it's designed simply to preserve the good life for those who already have it." (Dionne 1999, p.A29).

I explore these Smart Growth tensions with my analysis. I engage with other researchers debating the equity impacts of Smart Growth by examining the socio-spatial outcomes of the Central Puget Sound's regional growth planning efforts. Further, as addressed in the next section, I use the theory and methods associated with environmental inequality formation to explore Smart Growth's impact on environmental exposure.

2.2. Environmental Inequality Formation

Environmental justice scholarship has its roots in the study of distributional inequities, or the maldistribution of environmental goods and bads. Robert Bullard conducted the seminal study in the field of environmental justice scholarship, examining solid waste disposal siting in Houston, TX (1983). Bullard found that although Blacks made up just over one-fourth of Houston’s population, five out of five city-owned landfills (100 percent) and six of the eight city-
owned incinerators (75 percent) were sited in African American neighborhoods. This study, as well as the Warren County, North Carolina protests over a polychlorinated biphenyl (PCB) landfill, provided the impetus for a 1983 U.S. General Accounting Office (GAO) study, *Siting of Hazardous Waste Landfills and Their Correlation with Racial and Economic Status of Surrounding Communities*, which found that there was a correlation between the location of hazardous waste landfills and the racial and economic status of the surrounding communities in eight southeastern states (Peach 1983). Soon after, the Commission for Racial Justice produced the 1987 report *Toxic Waste and Race*, the first national study to correlate waste facility sites to minority populations (Chavis 1987).

These early studies used a 'unit hazard coincidence method' that compared the prevalence of economically disadvantaged communities and communities of color within geographies that hosted pollution generation or storage facilities, in order to determine whether disproportionate distribution was present (Chakraborty *et. al* 2011; Pastor, 2014; Sze and London 2008). Generally, the studies focused on a single type of hazard (e.g., hazardous waste treatment, storage and disposal facilities or toxic release inventory sites) and equated proximity with exposure (Holifield 2014). First, the location of the hazard would be identified. Then, the economic and racial makeup of the population surrounding the facility would be evaluated, based on attributes from the United States’ Census (Holifield 2014). Studies used a variety of geographic containers (e.g., County, Zip Code, or various Census geographies) to determine the extent of the area surrounding the hazardous facility (Chakraborty *et al* 2011; Walker 2012). Traditional statistical techniques like linear correlation and regression were two primary methods used to assess distributional inequality.
Over time, a large number of studies, using different methods and data sources, found evidence of disproportionate exposure to pollution hazards. Yet, controversy remained on two key fronts: 1) whether race and ethnicity or class was a better predictor of exposure disparities (Anderton et al. 1994, Mohai and Bryant 1992; and Zimmerman 1993), and 2) whether facility siting targeted disadvantaged populations or attracted these populations after siting, known as the 'siting versus move in' or 'Chicken or Egg' debate (Mohai and Saha 2015; Been 1994; Been and Gupta 1994; Oakes et al. 1996; Pulido 2000; Saha and Mohai 2005).

With respect to the 'race-class' divide, research has gradually shifted to acknowledge that multiple, overlapping positions within society may increase vulnerability. While previous studies highlighted the independent roles of race, class, and immigrant status in environmental inequality outcomes, new studies are increasingly taking an intersectional approach (Downey and Hawkins 2008; Mohai et al. 2009; Pulido 1996) that explores the relationships among race, class, immigrant status, and environmental inequality.

With respect to the 'siting-move in' divide, research has also pivoted to examine how inequalities formed over time. Coined by Pellow (2000) as 'Environmental Inequality Formation' (EIF), this new, more holistic research approach focuses on the mechanisms that lead to inequality. As described by Pellow (2000), inequalities form "when different stakeholders struggle for access to scarce resources within the political economy, and the benefits and costs of those resources become distributed unevenly" (p. 589).

Under this new line of inquiry, researchers began to examine how environmental inequality forms over time using quantitative approaches combined with qualitative, historical and critical methods. Analysts have attempted to identify the processes that contribute to environmental inequality. As articulated by Mohai and Saha (2015, 2005) and Ard (2015), this
line of inquiry has identified three different categories of explanation: economic or rational choice, sociopolitical, and racial discrimination. In this tradition, Stroud (1999) exposed the long history of zoning and development decisions, coupled with discriminatory housing practices, to explore the cultural and institutional forces at work in creating environmental inequalities in Portland, Oregon. Pulido (2000) examined regional land use, zoning and socioeconomic changes in Southern California over time, to show the role of white privilege in environmental inequality formation. Similarly, Szaz and Meuser (2000) used a historical, critical analysis combined with spatial quantitative analysis to explore the processes leading to inequality formation in Santa Clara County, California.

With respect to sociopolitical explanations, three different conceptualizations have emerged of the processes promoting disparate siting: 1) environmental gentrification, 2) ethnic churning, and 3) residential sorting. Studies examining environmental gentrification have focused on whether low-income and minority residents are displaced from neighborhoods after locally undesirable land uses are cleaned up and reused (Banzhaf and Walsh 2006; Essoka 2010; Gamper-Rabindran and Timmins 2011). Some researchers have stressed the adverse effects of ethnic churning, shifts in demographic composition that occur over time as one race or ethnicity replaces another, which subsequently impact the capacity of neighborhoods to resist siting of environmental hazards (Pastor et al. 2001; Morello-Frosch et al. 2002). Finally, other researchers and environmental activists have stressed that when risks are perceived from hazardous sites, those who are able to move out do so, leaving those who cannot, typically low-income and minority residents (Pellow 2000; Been 1994; Been and Gupta 1997; Oakes, Anderton and Anderson 1996).
Despite the growth in this type of critical analysis, in their meta-analysis of longitudinal studies Mohai and Saha (2015) argued that a lack of longitudinal studies, as well as methodological gaps and inconsistencies, have contributed to confusing and contradictory findings about the processes influencing environmental inequality. One of the recommendations stemming from Mohai and Saha’s (2015) research was the need for more "longitudinal analyses that take into account the history of zoning and land use decisions…to help explain the creation of ['sacrifice'] zones that then become magnets for future noxious facility siting" (p. 7).

Another shift in the research has been to examine how multiple environmental hazards cumulate in the risk profiles of some communities but not others (Brulle and Pellow 2006; Chakraborty and Maantay 2012; Corburn 2002; Sexton 2012). While early studies examined the unequal exposure some communities face due to their proximity to a certain type of pollution source, such as hazardous waste transfer, storage, and disposal facilities, increasingly studies are looking at cumulative risk exposure, recognizing that there are multiple environmental stressors present in communities that can lead to disparate impacts.3

Researchers have also found that industrial air pollution is highly skewed (Boyce et. al 2016; Collins 2016). Due to this unevenness, methods that focus on average values have been

3 It should be noted that within environmental justice discourse there has been an expanding definition of justice, from original studies which focused on distributional inequalities, to new research that is now examining issues of participation (procedural justice), capabilities, and recognition (Schlossberg 2007). This has resulted in a parallel expansion of the issues with which environmental justice engages, expanding from toxic and hazardous waste impacts in low income and communities of color to now include environmental inequalities in areas such as transportation, open space, health, housing, and smart growth/land use, water, and brownfields, to name a few (Sze and London 2008). This study focuses on risks from environmental hazards, though the methods could be expanded to include additional analysis into these expanding issue areas.
found to overlook disparities that exist at higher levels of pollution (Abel 2008; Abel and White 2015; Gochfield and Burger 2011). As a result, research has begun to consider how extreme unevenness in exposure disproportionately impacts different communities.

My research responds to this theoretical and methodological foundational work in three ways: 1) by taking a longitudinal approach that examines outcomes from regional planning decisions over time; 2) by using data and methods that respond to concerns with unit hazard coincidence, examine skewness in pollution exposure risk, and incorporate analysis of cumulative hazards; and 3) by incorporating an intersectional approach that explores the relationships among race, class, immigrant status, and environmental inequality.

First, my research is focused on regional land use planning and examines how regional land use decisions influence the environmental riskscape and contribute to environmental inequality formation, using a longitudinal approach. In particular, I focus on the role of the region-based Smart Growth planning. My research is situated in two key on-going debates about the effectiveness of Smart Growth in mitigating environmental exposure risks: 1) whether the compact urban form envisioned by Smart Growth ameliorates or exacerbates environmental exposure inequalities, and 2) whether the outcomes stemming from changes in the industrial landscape associated with Smart Growth strategies, including infill and brownfield redevelopment, are equitably distributed.

Debate concerning environmental exposure inequality has largely been centered on the appropriate measurement to use to compare compact versus sprawling development patterns. Bereitschaft and Debbage (2013), in their examination of the relationships between urban form and air pollution among 86 U.S. metropolitan areas, found that metropolitan areas that exhibited higher levels of urban sprawl generally exhibited higher concentrations and emissions of air
pollution when controlling for population, land area, and climate. Their findings were consistent with Ewing et al. (2003), but differed from other researchers who examined not just air pollution concentration, but also exposure (Clark et al. 2011; Schweitzer and Zhou 2011). In their comparison of air quality conditions in compact versus sprawled regions, Schweitzer and Zhou (2010) found that exposure to fine particulates, particularly for impoverished seniors and children, was higher in compact regions.

Debate focused on the outcomes stemming from changes in the industrial landscape is centered around the distribution of the benefits and costs. Smart Growth proponents contend that strategies focused on infill and redevelopment provide the opportunity to remove existing health hazards and improve quality of life (McConville 2013). This stems from the opportunity that redevelopment provides to clean up former contaminated and underutilized sites that pose hazards to neighboring communities. In contrast, Smart Growth has been critiqued for its lack of emphasis on industrial retention and revitalization and for encouraging redevelopment of existing industrial lands near urban cores (Chapple 2014; Leigh and Hoelzel 2012). Critics argue that conversion of industrial lands and displacement of manufacturing, warehouse and other related facilities have numerous adverse impacts, including: 1) displacement of living wage jobs, 2) reduction in access to employment, especially for workers without access to private transportation, and 3) increased travel for freight trucks, resulting in higher diesel particulate emissions. I examine changes in industrial and land use patterns over time and assess how these changes may be associated with social and environmental equity outcomes.

Second, the data and methods that I use are designed to address the limitations of early studies, which include use of unit-hazard coincidence methods, focus on one type of hazard, and analysis based on averages rather than areas of high exposure risk. I incorporate facility-based,
modeled air pollution data (the Risk Screening Environmental Indicators Microdataset) that estimates the toxic concentration levels emanating from multiple neighboring industrial facilities on a grid-cell across the region, reducing concerns about unit-hazard coincidence studies that have been highlighted by Mohai and Saha (2015). Further, I explore how multiple environmental hazards combine to pose cumulative impacts, with a particular focus on toxic hotspots, where extreme pollution hazard is located.

In addition, I incorporate an intersectional approach, using numerous variables as proxies for race, class, and immigrant status to analyze the socio-spatial equality outcomes, and compare those to environmental exposure. Finally, as addressed in the next section, I incorporate health data to examine health outcomes over time, as well as their relationship with socioeconomics and environmental exposure.

2.3. Health Disparities and the Social Determinants of Health

Over the last several decades, scholars have learned that a person's Zip Code is a better predictor of health outcomes than their genetics (Roeder 2014; Simms 2016). In response to this finding, public health agencies have begun to pivot their research and programs to focus on social determinants of health (CDC 2016; WHO 2016). Social determinants of health are defined in Healthy People 2020 (U.S. Department of Health and Human Services 2014), the nation's 10-year plan for health promotion and disease prevention, as "...conditions in the environments in which people live, learn, work, play, worship, and age that affect a wide range of health, functioning, and quality-of-life outcomes and risks" (sec. Overview: Understanding Social Determinants of Health). Conditions include the social, economic and physical characteristics of the places in which people live, work, learn and play (Alder and Newman 2002; Braverman 2006; Wilkinson and Marmot 2003).
One of the clearest determinants of health disparities is socioeconomic disadvantage (Link and Phelan 1997; Bose and Diette 2016). Research has concluded that the factors that comprise socioeconomic status also influence health outcomes (Lynch and Kaplan 2000; Adler and Stewart 2010), with educational attainment and income disparities being two key factors that have been studied and shown to influence health outcomes (Lynch and Kaplan 2000; Krieger et al. 1997; Meyer et al. 2013; Braverman et al. 2011). Moreover, the socioeconomic conditions of our communities, places where people live and work, have been shown to have more influence on health outcomes than personal socioeconomic position (Ross and Mirowsky 2008; Macintyre et al. 2002). Communities with the lowest educational achievement and income "are the most common and persistent among subgroups that systematically exhibit the poorest health" (Meyer et al. 2013, p. 15). Race, with its relationship to socioeconomic status, also influences health, with racial and ethnic minorities exhibiting disproportionate rates of respiratory disease and morbidity (Bime 2016; Bose and Diette 2016).

Another key determinant of health is the physical settings in which people interact, including the natural and built environments. Examples of physical determinants include neighborhood design, building design, and exposure to pollution (Alder and Newman 2002). These factors can all impact health outcomes. In particular, the HEI Panel on the Health Effects of Traffic-Related Air Pollution (2010) concluded there is a causal association between exposure to traffic-related air pollution and exacerbation of asthma. Further, communities with lower socioeconomic status, in turn, are more likely to live near highways, industrial areas, and in poor housing conditions.

In addition, research has also connected poor housing quality with health outcomes. People residing in inadequate housing may be more exposed to pests and mold, lead paint, or
other hazards that exacerbate asthma, limit intellectual development, and contribute to other infectious and chronic health diseases and injuries (Bime 2016; CDC 2011). Housing quality is generally poorer in communities with low socioeconomic status (Alder and Newman 2002). In addition to housing conditions, availability and quality of neighborhood services (e.g., schools, transportation, food, medical care, etc.) can also shape a person's access to opportunity and resulting health (Braverman et al. 2011).

Finally, exposure to air pollutants, such as particulate matter and ozone, have been linked to a number of adverse health outcomes, particularly respiratory and cardiovascular conditions (CDC 2011; Bose and Diette 2016). Industrial facilities and motor vehicles are key contributors to particulate matter and ozone production (CDC 2011; Bose and Diette 2016). Again, there is evidence of disparity in exposure to air pollutants. As noted by Bose and Diette (2016), "...inequalities in the environment that characteristically divide groups often coexist with differences in air quality, which in turn lead to disparities in respiratory health" (p. 47). Health disparities are theorized to be influenced by three key mechanisms: differential levels of exposure; differential levels of susceptibility, and differential levels of adaptability (Bose and Diette 2016). Differential exposure results from certain groups being more exposed to air pollution sources, typically as a result of their socioeconomic status or race/ethnicity. Meanwhile, a pollutant may have different health impacts depending on a person's vulnerability, which is in turn impacted by a number of personal, social and environmental factors. Lastly, a person's ability to adapt to exposure risk is affected by their social standing.

As an example, Yip et al. (2011) compared populations living in non-attainment areas for particulate matter and ozone, finding that minorities, particularly Asians and Hispanics, were more likely to live in a nonattainment area. In addition, lower levels of completed education
were associated with non-attainment for particulate matter, but not for ozone. In contrast, persons in the highest income category were more likely to reside in non-attainment areas for both particulate matter and ozone. These results were noted by the CDC to likely "reflect the demographic distribution of persons who live in predominantly urban areas. The populations in urban centers and metropolitan areas tend to be diverse, with areas of wealth integrated with those in poverty" (Yip et al. 2011, p. 31). But, residence in a nonattainment area does not equate to exposure, which may vary across a region (Yip et al. 2011) and among individuals, due to the compounding of different stressors that may make some more vulnerable to the effects of pollution (Walker 2012).

Yet, despite findings by public health scholars that highlight the importance of planning policy decisions in influencing health outcomes, interdisciplinary collaboration between professionals working in public health and planning fields is still limited (Corburn 2004; Sandlin 2005). As noted by Sandlin (2005), "…within planning practice the interdisciplinary bridge to environmental health may not be adequately understood, yet there may be significant environmental health consequences of planning actions" (p. 9-10). Environmental impact statements and similar environmental reviews have been used in contemporary planning work to assess the impacts of plans, programs, and projects, using a risk assessment approach to consider impacts to human health (Corburn 2004). Risk assessment has been criticized for many reasons, including failure to consider disproportionate exposures and cumulative stressors that may place some populations at greater risk, as well as take into account evidence from non-experts (Corburn 2004). As opined by Corburn (2004), "…wholesale adoption of practices such as EIS and risk assessment leads to planning becoming disconnected from environmental health" (p. 542).
New planning models, such as Smart Growth, New Urbanism, and Transit-Oriented Development, have attempted to move beyond risk assessment and further incorporate principles of health into the design of places by emphasizing what are known as the '5 d's of development': density, diversity, design, destination, accessibility, and distance to transit (Cervero and Kockelman 1997; Ewing and Cervero 2001, 2010; Ewing et al. 2012). These '5 d's are theorized to promote active transportation and improve health outcomes (Ewing et al. 2012). They are also theorized to reduce harmful air pollution associated with vehicular travel, as sprawling development is replaced with more compact development that reduces travel needs (Ewing et al. 2012).

Yet, additional research into the health implications of urban planning decisions is still needed in order to better understand the impacts from different planning strategies and implement effective interventions (Giles et al. 2010; Lindberg et al. 2010). While many studies have focused on obesity-related outcomes stemming from implementation of Smart Growth strategies (Hutch et al. 2011), fewer studies have researched air quality-related outcomes resulting from compact development and redevelopment and, in particular, whether disparities emerge or are exacerbated under these planning strategies (Jackson et al. 2011). My research focuses, in part, on one type of health outcome, asthma hospitalization, in order to examine disparities and associations with social and environmental factors within a Smart Growth planning context.

2.4. Pugetopolis

Pugetopolis is the informal descriptor used to denote the metropolitan region centered around the City of Seattle, which grew rapidly in the 1950s (Moudon and Heckman 2000). Officially known as the Central Puget Sound region, it is the major metropolitan region in Washington State. It is the home to a majority of the residents in Washington State, who reside
in cities and suburbs located west of the Cascade foothills extending to Puget Sound, stretching almost 80 miles north to south along Puget Sound's shores. Most Puget Sound communities lie on either side of the north-south Interstate Highway 5 corridor that serves as the major traffic thoroughfare of the state.

The region comprises parts of four counties (King, Kitsap, Pierce and Snohomish), anchored by three older, former industrial cities of Tacoma, Seattle, and Everett and containing over 80 cities (Figure 2). The area nearly tripled in population over the five decade period from 1960 to 2010 and now contains almost 4 million residents (PSRC 2016a), the majority of whom reside in the centrally located King County (53%), followed by Pierce County to the south (21%), Snohomish County to the north (19%) and Kitsap County to the west (7%). King County has the highest density (970 persons/square mile), followed by Kitsap County (654 persons/square mile), Pierce County (497 persons/square mile), and Snohomish County (363 persons/square mile) (PSRC 2016a).

The region is home to many new economy jobs, including technology firms like Microsoft and Amazon. These join other key industries, like forestry leader Weyerhaeuser, and aerospace leader Boeing, the leader's largest employer. The region contains two deepwater ports, at Seattle and Tacoma, making the region a major center for international trade. The region also has several major military installations, including McChord Air Force Base and Fort Lewis Army Base south of Tacoma, Naval Station Everett, Naval Base Whidbey Island, Naval Base Kitsap (Bangor) and Naval Base Bremerton.
Figure 2: Cities and Counties of the Central Puget Sound Region. Source: Puget Sound Regional Council (PSRC)
Since the 1950s, the region's suburbs have grown substantially, with both residential and employment centers migrating to the suburbs that surround the major cities. It is estimated that approximately 70 percent of the population now lives outside of the central cities of Seattle, Tacoma and Everett.

2.4.1. Regional Planning in Central Puget Sound

One part of this study focuses on policy decisions or non-decisions occurring at the regional level, or as Dye (1987) defines policy, "what governments choose to do or not do" (p. 3 as quoted in Clemons and McBeth (2001)). The region is used as the scale for analysis based upon recommendations from other studies that have indicated that environmental inequality should be considered in the context of industrial clusters, economic development and traffic patterns that exist in a metropolitan area, which are all influenced by larger processes of economic geography (Pastor et al. 2007; Pastor 2014). As a result, this next section turns to provide a brief policy analysis of regional planning in the Central Puget Sound.

In this region, the Puget Sound Regional Council (PSRC) acts as the regional growth, economic development and transportation planning authority. The mission of PSRC is to "ensure a thriving central Puget Sound region through planning for regional transportation, growth management and economic development" (PSRC 2016b, pg. 1). PSRC is a member-based regional government agency with several state and federally-designated roles. Its members include the four counties and cities within their boundaries, as well as federally-recognized tribes, port and transit districts, and the Washington State Department of Transportation and Transportation Commission. In addition, several associate members have joined, including universities, the Puget Sound Partnership, and others. PSRC is governed by a General Assembly
and an Executive Board. Each member of PSRC is a voting member of the General Assembly, whose role is to vote on major decisions, establish a budget, and elect new officers.

The Executive Board serves as the governing board and members are appointed by their respective General Assembly representative – thus it is the Executive Board that makes the key policy decisions for PSRC. Decision-making by both of these bodies is based upon population-weighted voting, which favors large population centers in the region. The Transportation Policy Board and Growth Management Policy Board are two supporting policy advisory boards that provide recommendations on key transportation and growth management issues to the Executive Board. These boards are comprised of PSRC’s member jurisdictions, and also include tribes, regional business, labor, civic, and environmental groups, as well as voting members representing each caucus of the state Legislature.

PSRC focuses on three functional areas: transportation, economic development, and growth management. First, PSRC functions as the federally-designated Metropolitan Planning Organization (MPO), responsible for allocation of federal transportation funding, as well as the state-designated Regional Transportation Planning Organization (RTPO) responsible for allocating funding for regionally significant transportation projects. In support of these functions, PSRC creates a regional long-range transportation plan, Transportation 2040, that identifies needed investments to meet projected housing and employment growth (PSRC 2016b). PSRC is also responsible for conducting an air quality conformity analysis to demonstrate that the planned long-range transportation network, which is guided by the regional growth framework, conforms to the State Implementation Plan for Air Quality (SIP), providing a mechanism to ensure that transportation activities are reviewed for their impacts on air quality prior to funding or approval. This process is intended to ensure that growth and transportation
are managed in a manner as to ensure compliance with the National Ambient Air Quality Standards under the Clean Air Act.

Second, in its role in economic development, PSRC provides administration, management, and operations support for the Central Puget Sound Economic Development District, including development of a comprehensive regional economic development strategy (CEDS), which enables the region to qualify for federal funding assistance from the US Economic Development Administration (PSRC 2015).

Finally, land use planning in the Central Puget Sound is conducted under the statewide planning enabling legislation (RCW 36.70) and the Growth Management Act (RCW 36.70A). Washington State passed the Growth Management Act (GMA) in 1990, in response to substantial population growth, escalating property taxes, housing costs, traffic congestion, and loss of wetlands, farms and forests (Tovar 2015). Under GMA, Washington State requires Counties and Cities of certain size or population growth to prepare a Comprehensive Plan, which establishes the community's 20-year vision for growth. Comprehensive plans, infrastructure planning and budgeting, and land use regulations must be integrated and consistent with each other. Further, growth must be contained through Urban Growth Boundaries, which are established to contain 20-years of growth and are designed to prevent sprawl and allow for efficient use of land for development purposes. Most relevant to this study, GMA has provisions in place to require coordination of planning efforts among local governments. In the Central Puget Sound region, this coordination is conducted by PSRC.

As the regional growth management planning organization, PSRC creates and maintains a regional growth management strategy, *Vision 2040*, that is based on and developed from local jurisdiction comprehensive plans and focuses on regional issues such as transportation, open
space, air and water quality, economic development and regional facilities. *Vision 2040* functions as the region's coordinated growth management, environmental, economic and transportation strategy (PSRC 2015). Through the regional growth strategy, PSRC complies with the requirements of GMA to develop multicounty planning policies that provide a common framework and insure consistency in planning efforts (RCW 36.70A). PSRC also audits county and city local comprehensive plans to ensure that these plans conform to the regional growth strategy, as well as provisions of the GMA related to transportation.

Over the last 20 years, the region’s growth management strategy has been planned within a framework of Smart Growth. The Central Puget Sound Region was one of the first regions in the nation to implement Smart Growth planning as part of its *Vision 2020: Growth and Transportation Strategy*, first adopted in 1990 (Drewel 2011). *Vision 2020* was adopted in response to the growth boom of the 1980s; the region grew both 'up' and 'out' (Calthorpe and Fulton 2001), resulting in an imbalance of jobs and housing, with substantial new employment in the Seattle core, new job centers in older suburbs, and low-density development on the periphery. The resulting traffic congestion and other environmental concerns stimulated public concern over growth and sprawl, eventually leading to the passage of a statewide initiative to create a growth management law and, within the Puget Sound Region, an ad-hoc effort to develop a regional growth strategy. *Vision 2020* outlined several principles to direct and manage growth, including:

- Containing urban sprawl through the use of urban growth boundaries;
- Focusing development into designated centers which were organized around a hierarchy of places, including neighborhoods within Seattle as well as suburban downtowns throughout the region;
- Creating a mix of residential and employment uses; and
- Creating a regional transportation strategy connecting urban centers with multimodal transportation systems (Calthorpe and Fulton 2001).
Since that time, these principles have been implemented through coordinated regional planning and investments. The original Vision 2020 objectives were affirmed and strengthened in later regional planning documents, including Vision 2040, which continues to manage urban growth within the Smart Growth framework (Dierwechter 2014; Fox 2010; Herrscel 2013; Margerum et al. 2013).

Vision 2040, adopted in 2008 by the PSRC General Assembly, commits the region to substantially accommodating more than one million people projected to be added to the current population by 2040 within the current metropolitan urban growth boundary. The plan is broken down into three key sections, vision, policy structure, and implementation, which together describe how the region meets this growth challenge.

First, the plan contains a vision statement that provides an overview of the guiding direction for the planning period, stating:

Our vision for the future advances the ideals of our people, our prosperity, and our planet. As we work toward achieving the region’s vision, we must protect the environment, support and create vibrant, livable, and healthy communities, offer economic opportunities for all, provide safe and efficient mobility, and use our resources wisely and efficiently. Land use, economic, and transportation decisions is integrated in a manner that supports a healthy environment, addresses global climate change, achieves social equity, and is attentive to the needs of future generations (PSRC 2009, p. xi).

Next, the plan also contains a policy structure, composed of regional goals which express desired outcomes for specific policy areas and multicounty policies that provide overall guidance and direction for policy-making at the local and regional level. The goal and policy structure is guided by principles of sustainability and is "… developed with attention to social equity and environmental justice" (PSRC 2009, p. 30).

A core goal of Vision 2040 is to focus future growth into centers. These centers are
…intended to play an important role in shaping future growth patterns. By absorbing new jobs, population, and housing, centers can help protect natural resource lands from growth and provide focal points for public investment in infrastructure. (PSRC 2014, p. 1).

In a review of urban centers entitled the 2013 Regional Centers Monitoring Report, PSRC lists the 'triple bottom line' benefits of this approach to growth management and regional planning:

Centers allow cities and other urban service providers to maximize the use of existing infrastructure, make more efficient and less costly investments in new infrastructure, and minimize the environmental impact of urban growth. Research finds that a centers-based growth strategy has the potential to protect land and water resources, reduce air quality and greenhouse gas emissions, support the region's economy and property values, and is a more socially equitable approach than dispersed growth (PSRC 2014, p. 3).

Two different types of centers form the basis of this policy objective: regional growth centers and regional manufacturing industrial centers.

The first type of center, regional growth centers, are conceptualized as areas within major cities where housing, jobs, shopping, entertainment and other services are located in close proximity, resulting in accessible communities that reduce reliance on vehicular travel and, as a result, reduce air emissions and generate health-related benefits from increased walking, biking, and transit use. Vision 2040 has a stated goal to "direct growth and development to a limited number of designated regional growth centers" (p. 48). The region has adopted 29 regional growth centers, which are intended to serve as urbanized areas that absorb housing and employment growth and "create walkable, compact, and transit-oriented communities" (PSRC 2009, p. 45). The majority of these centers, 21 of 29, were established in 1995 with the adoption of the Vision 2020, the predecessor to the current regional growth strategy. Six additional centers were established between 2003 and 2007, and a final two centers were established in 2014 and 2015 (Figure 3).
Figure 3: Central Puget Sound Regional Growth Centers
The second type of center, regional manufacturing industrial centers, is conceptualized as areas where existing centers of intensive manufacturing and industrial activity are preserved, in order to meet employment and regional development goals. Vision 2040 has a stated goal to "maintain and support viable regional manufacturing/industrial centers to accommodate manufacturing, industrial, or advanced technology issues" (p. 49). The region has adopted eight manufacturing industrial centers. The majority of these centers, 7 of 8, were established in 2001 and 2002 as part of the region's transportation planning efforts. An additional center (South Kitsap) was identified in 2003 (Figure 4).

Since research began, an additional manufacturing industrial center has been designated, in the Summer-Pacific area.
Figure 4: Industrial Zoning as of 2013
In addition to the regional growth centers and manufacturing industrial centers, Vision 2040 also contains a number of policies organized around six major topics, including: environment, development patterns, housing, economy, transportation, and public services. Equity and environmental health principles appear as part of the environment and housing goals and policies, with the following examples:

- **MPP-En-4**: Ensure that all residents of the region, regardless of social or economic status, live in a healthy environment, with minimal exposure to pollution (PSRC 2009, p. 30).
- **MPP-En-18**: Reduce levels for air toxics, fine particulates, and greenhouse gases (PSRC 2009, p. 40).
- **MPP-DP-44**: Incorporate provisions addressing health and well-being into appropriate regional, countywide, and local planning and decision-making processes (PSRC 2009, p. 59).
- **MPP-H-1**: Provide a range of housing types and choices to meet the housing needs of all income levels and demographic groups within the region.
- **MPP-H-2**: Achieve and sustain — through preservation, rehabilitation, and new development — a sufficient supply of housing to meet the needs of low-income, moderate-income, middle-income, and special needs individuals and households that is equitably and rationally distributed throughout the region (PSRC 2009, p. 69).
- **MPP-Ec-8**: Promote economic activity and employment growth that creates widely shared prosperity and sustains a diversity of family wage jobs for the region’s residents (PSRC 2009, p. 74).
- **MPP-T-7**: Develop a transportation system that minimizes negative impacts to human health (PSRC 2009, p. 81).
- **MPP-T-22**: Implement transportation programs and projects in ways that prevent or minimize negative impacts to low-income, minority, and special needs populations (PSRC 2009, p. 83).

Finally, the plan contains a set of implementation measures that identify specific actions and responsibilities to implement the vision and policies. One of the key implementation strategies to support center development is to direct available funding, including federal, state,
regional and subregional funding to support infrastructure and services within these centers. As noted in PSRC’s 2015 year-end report (PSRC 2015):

Given the importance of regional centers in accommodating future population and employment growth, they are prioritized for regional and countywide transportation and economic development funding. (p. 12).

Other implementation actions are identified in Vision 2040; the following focuses on those that relate to equity and environmental health principles noted above. In terms of specific actions to implement these policies, only three policies had specific implementation actions identified: MPP-En-18, H-1 and H-2. The other policies, in particular policy MPP-En-4 that addresses environmental inequality most specifically, had no specific implementation actions identified in the plan. For Policy En-18, the plan identifies a project to work with Puget Sound Clean Air Agency (PSCAA) to identify steps to improve air quality beyond the minimum standards. For Policies H-1 and H-2, the plan identifies the need to create a regional housing strategy. Thus far, PSRC has completed a Housing Needs Assessment and has developed guidance on innovative housing policies and tools to promote a range of affordable housing choices to meet the needs of all current and future residents (PSRC 2015). Though not specifically addressed through an identified implementation activity, PSRC obtained a Community Transformation Grant to develop a toolkit (Planning for Whole Communities) for local jurisdictions to promote health, equity, and sustainability in plans, programs, and policies.

Vision 2040 also contains performance measures to assess how the region is meeting the goals and policies. For air quality, the performance measure used to evaluate air pollution reduction is the number of unhealthy air days, as tracked by the PSCAA. Housing affordability is measured by housing supply and distribution. Community health was to be evaluated by an analysis of Body Mass Index. No specific measures were developed for social equity.
Thus, a brief review of the policies contained in *Vision 2040* would suggest that social equity and environmental health are key concerns. According to PSRC documents, compact growth, as supported by the regional growth centers and manufacturing industrial centers, is considered more equitable than dispersed growth, the plan has been sustainably designed in consideration of the three Ps (people, prosperity and planet), and developed with attention to social equity and environmental justice. But, how specifically were issues of social equity and environmental justice taken into account as part of the plan creation, adoption, and implementation process? On what basis did PSRC conclude that compact development is more socially equitable? In order to address these questions, I now examine the approval process for *Vision 2040*, as well as adoption criteria for designating new centers and certification process for existing centers.

As part of the development and adoption process for *Vision 2040*, PSRC initiated a number of different evaluation processes aimed at ensuring that the proposed policy strategies contained in the plan would minimize impacts, including environmental and social impacts. Specifically, PSRC completed an Environmental Impact Statement (EIS) to satisfy the State Environmental Policy Act (RCW 43.21C) requirements. As part of this analysis, three key topic areas were addressed that are of relevance: Environmental Justice, Air Quality and Environmental Health.

In the Environmental Justice analysis, PSRC documents the outreach process that was used to involve minority and low-income populations in the decision-making process, including survey research, focus groups, key informant interviews, translation of materials, and focused workshops done collaboratively with community organizations. According to PSRC, this outreach helped to identify the key issues of concern amongst minority and low-income
populations, including: loss of affordable housing and reduced access to employment, services, and the quality of transit services. Many of these issues were identified as being interconnected – for example, displacement due to rising housing costs may cause low-income residents to move to less dense or rural communities, where there is reduced transit access. Further, though many in the region may live in close proximity to transit, the service may not be frequent or convenient enough to meet their needs. Of note, the focus groups considered access to jobs for minority and low-income groups to be a major issue, to which PSRC noted that "the block groups with the highest concentrations of minority and low-income populations tend to be near urban centers and manufacturing/industrial centers" (PSRC 2008, p. 6-25) which provide employment opportunities. In the EIS, PSRC identified a number of potential impacts with the alternatives, including: increased demand for land and building sites, increasing rents and land values, displacement of low-income populations in urban activity centers by high income residents. As noted in the EIS:

The potential for such displacement to occur tends to rise during periods of rapid economic growth, when housing construction often lags behind the demand created by the influx of new workers and their families. The displacement process can be mitigated by active efforts to preserve and build affordable housing opportunities in areas experiencing such cost pressures (PSRC 2008, p. 6-29).

Implementation of a regional housing strategy that would preserve existing affordable housing and create new low-income housing options is identified as a potential mitigation measure to address this impact. Impacts from traffic congestion are also addressed, yet the EIS notes that focused growth alternatives would likely have the most transportation benefits for minority and low-income populations due to reduced need for automobile dependency for those residents residing in new mixed-used walkable communities. Air quality impacts in congested areas are identified as a potential impact to vulnerable populations, yet can be mitigated by
Air-quality-compatible land use planning, technological advances to reduce vehicle pollutants, air filtration systems, buffer zones, and building design for crosswind removal of pollutants are some strategies to mitigate air quality impacts in urban areas (PSRC 2008, p. 6-30).

In terms of environmental health, the EIS noted that

Given the historic presence of industry in the part of the region first developed (such as the metropolitan and core cities), the alternatives that focus the most growth into these cities would increase the potential for exposure to hazardous materials (PSRC 2008, p. 6-31-32).

Further, the EIS states:

For all alternatives, there are health disparities that low income and minority groups are likely to experience, in part because of environments that do not promote physical activity or that expose them to air pollution. The Preferred Growth Alternative and alternatives that focus people into more compact communities can often create more opportunities for walking and recreation, although air pollution exposure could also increase (PSRC 2008, p. 6-32).

The EIS notes that cumulative impacts are possible, particularly for plans that concentrate growth in areas with relatively high concentrations of minority and low-income populations, if adequate coordination and mitigation measures are not implemented. Despite a lack of detailed mitigation measures, the 2008 EIS concludes that disproportionately high and adverse effects on minorities and low-income populations are not anticipated to result.

In the Air Quality analysis, the EIS specifically evaluates region-wide CO₂ and PM₂.₅ levels that are projected to result from the different growth alternatives under consideration, as well as ozone, CO, and PM₁₀ emissions in their respective maintenance areas. Localized impacts from compact growth were addressed in a supplementary analysis, *At The Microscale: Compact Growth and Adverse Health Impacts* (Sandlin 2005), which was conducted to examine the relationship between traffic, localized air quality and land use patterns. This analysis was conducted in response to growing concerns about traffic-related 'hot spots' of poor air quality
that were the result of heavy traffic associated with high population and employment density. This report, summarizing the state of research at the time, determined that there may be localized impacts to air quality and resulting adverse health impacts from the compact growth patterns being considered.

The EIS references this document, and identifies several mitigation strategies that may be considered to mitigate the potential impacts, including greater consideration of the proximity of sensitive populations to land use development, installation or preservation of trees and vegetation, consideration of cumulative impacts of marine and air traffic, and continued enforcement of burning bans, and limits on smoke from wood stoves and fireplaces. Other mitigation measures already in place were recommended to be continued, including the state's emission check program, trucking idling and Clean Car standards, as well as clean fuel technology upgrades. The EIS emphasized that future project-level environmental reviews would determine if air quality standards were exceeded at specific locations. As a result, the EIS concluded that "If all proper mitigations are required as part of subsequent project-level actions, no significant unavoidable adverse air quality impacts are expected under any of the alternatives" (PSRC 2008, p. 5.4-14).

Finally, the Environmental Health section more specifically focuses on toxic and hazardous materials. With continued growth in the region, the EIS notes that there may be increased demand and pressure for manufacturing or processing activities that involve hazardous materials. In addition, this analysis focuses on the likelihood of encountering sties with previous contamination as well as the potential long-term benefits that may be obtained through cleanup of previously contaminated sites. If growth was focused in compact areas, the EIS noted that the urban centers are "… already more dense and tend to have higher levels of transportation
and industrial activity and resultant pollution" (PSRC 2008, p. 5.9-6). This section of the EIS provides a comparison of the environmental health risks posed by more compact versus more dispersed growth, stating:

> With increased development comes an increased risk to human health in the form of exposure to toxic or hazardous materials. The benefit of promoting growth within already developed metropolitan and larger cities is the decreased risk of contaminating less spoiled rural and open areas. However, when the risks to human health as a result of site contamination from hazardous materials are analyzed together, the differences between the alternatives are minimal (PSRC 2008, p. 5.9-8).

This section concludes by noting that human health impacts could be reduced by mitigation, but not wholly avoided.

Based in part on this analysis, the PSRC's Executive Board ultimately chose to move forward with a compact growth alternative, which forms the foundation of *Vision 2040* (PSRC Resolution A-08-04 as contained in PSRC 2009). While issues of social equity and environmental justice were analyzed and various equity and health impacts associated with compact growth were identified, the decision was made to approve the compact growth plan, in large part because it was argued that the impacts would be not to be significant. This determination was based on a number of assumptions, including:

- Adverse impacts were outweighed by other benefits, such as decreased reliance on automobile traffic and increased physical activity for residents in new compact growth communities, and
- Adverse impacts would be mitigated.

Smart growth planning has now been in place for over 25 years, providing the opportunity to gauge the success of long-term trends. In this study, I evaluate the claims about the benefits of the Smart Growth policies that form the backbone of *Vision 2040*, including the designation and implementation of regional growth centers and manufacturing industrial centers. First, I examine the neighborhood characteristics within the region as well as within regional
growth centers over time to determine who has benefited from the infill and redevelopment policies established under the plan. This analysis gauges whether the benefits associated with regional growth centers, including the opportunity for enhanced physical activity and access to job opportunities, are equitably distributed and, as such, provide an appropriate offset to identified risks, including increased pollution exposure. Second, I examine the regional pollution riskscape to assess the environmental outcomes and analyze whether air quality and environmental health impacts have been minimized and mitigated. My examination of the riskscape has two parts: first, I evaluate whether or not the riskscape has become more or less skewed over time; then, I conduct a cumulative assessment of different air quality-related environmental hazards to determine where the most concentrated regional risk is located. Finally, I examine health data over time to assess how air quality-related health conditions have changed. These separate analyses underlie my assessment of region's actions or inactions have resulted in equitable development.

Chapter 3. Data and Methods

The research is an exploratory, longitudinal analysis of the region designed to examine the socio-spatial outcomes of the Central Puget Sound's regional growth planning efforts; identify whether skewed environmental riskscape have formed in the Central Puget Sound region; and analyze the associations among the region's social equity, air pollution riskscape, and health outcomes. As discussed in Chapter 2, this analysis is based upon a normative model of equitable development, in which everyone should benefit from decisions that shape their communities. Demographic and socioeconomic characteristics are evaluated over time to reveal the socio-spatial consequences of regional policy decisions. In addition, air pollution related
hazards and risks are analyzed to determine if there is environmental inequality. Finally, regional health outcomes are analyzed, as well as the relations among socioeconomics, environmental inequality, and health outcomes.

The analysis of equitable development is organized by the following three topic areas (Figure 5) which provide three different lenses from which to view environmental inequality formation: policyscape, riskscape, and healthscape. First, the policyscape represents the spatial pattern of the region's social and demographic characteristics. This spatial pattern is both reflective and formative, meaning that the manner in which communities spatially sort themselves is both a consequence of social relations, as well as formative of them (Fincher and Iverson 2008). These patterns are influenced by a variety of factors, including long-term trends in settlement, migration and development, as well as political and economic actors exerting power and control through zoning, capital investments, and other mechanisms. This study focuses on demographic and socioeconomic patterns, as well as the regional planning policies that have played a role in constituting these patterns.

Second, the riskscape focuses on assessing the distribution of exposure risk, in particular whether the relative location of pollution sources and people has resulted in skewed exposure risks in which some neighborhoods face disproportionately higher risks. Finally, the healthscape focuses on the distribution of air-quality related health outcomes throughout the region. Trends in air-quality health outcomes are analyzed, together with analysis of the relationship of the region's policyscape and environmental riskscape to health outcomes.
The methods draw from different research fields (i.e. policy analysis, factorial social ecology, environmental inequality formation, and social determinants of health) that have been combined to address my research questions:

(4) How have the region’s socioeconomic outcomes changed over time?

(5) Do the location, distribution and intensity of environmental hazards in the region result in skewed riskscapes, in which some neighborhoods face disproportionately higher risks?

(6) What linkages exist among the socioeconomic status, air pollution distribution, and health outcomes?

To answer these questions, this study uses a multistep analysis process (Figure 6). The study begins with an analysis of regional demographic and socioeconomic patterns and trends, which is conducted in two integrated parts. First, I use factor analysis and cluster analysis to create
neighborhood typologies across the region. A neighborhood typology is developed to identify the key factors that distinguish different neighborhoods in the region; the typologies are analyzed to determine how socioeconomic and demographic characteristics are spatially distributed in the region, and how this distribution has changed over time. Second, I focus on demographic and socioeconomic patterns and trends in regional centers, discussed in Section 2.4.1. Using the regional neighborhood typology, I analyze changes in neighborhood characteristics that occur in proximity to regional growth centers and manufacturing industrial centers in order to consider the potential impacts of these decisions. The data and methods used to describe interactions between neighborhood characteristics and regional planning policies are discussed in Section 3.1.

In the second part of my study, I begin by analyzing regional exposure trends, focusing on the spatial distribution of large-scale point-source toxic air pollution producers in the region over time. Then, I combine large-scale point-source emitters with other information addressing

Figure 6: Overview of Study Process

Policyscape (Section 3.1)
- Regional Neighborhood Change
- Neighborhood Change in Regional Centers

Riskscape (Section 3.2)
- Exposure trends
- Cumulative environmental risk

Healthscape (Section 3.3)
- Trends in air quality-related health outcomes
- Relationship of policyscape and environmental riskscape with health outcomes
ambient air pollution and small-source point emitters to develop a cumulative air quality assessment that identifies hotspots of high exposure risk within the region. I then analyze the spatial distribution of pollution from these varied sources and compare this distribution to neighborhood characteristics in order to describe the environmental riskscape. The data and methods for the riskscape assessment are contained in Section 3.2.

In the final part of my study, I analyze air quality related health outcomes over time. I also analyze the relationship between health outcomes and the environmental riskscape as well as neighborhood characteristics. The spatial and statistical methods used to compare neighborhood characteristics to environmental risksapes are described in Section 3.3.

3.1.  **Policyscape of the Central Puget Sound Region**

   Neighborhood change can take many forms, but is described in this study in terms of upgrading and downgrading processes\(^5\). These processes can be influenced by a variety of different factors. This study focuses on processes of upgrading and downgrading in the Central Puget Sound region, both at the regional-scale and at a micro-scale, focusing on centers within the region where regional policy decisions have been implemented. The aim of this approach is twofold. The first objective is to better understand the general trajectory of neighborhood change in the region, while the second is to gain insight into the way that Smart Growth regional policies contribute to these processes.

\(^5\) Downgrading as used in this analysis refers to a relative decline in a neighborhood's socioeconomic status or housing value. Upgrading, in contrast, refers to a relative increase in a neighborhood’s socioeconomic status or housing value.
3.1.1. Regional Neighborhood Change

Neighborhood typologies are tools that enable researchers to analyze the spatial patterns of neighborhood structure and change (Delmelle, 2015 and 2016; Mikelbank 2011; Reibel 2011; Murdie et al. 2014, to name a few). Various methods can be used to create neighborhood typologies, including factorial social ecology and clustering analysis. As noted by Reibel (2011),

…recent studies applying factorial ecology generally use factor analysis of urban neighborhoods as a means to some other theoretical or analytical end, rather than as an end in itself.

This is the case with my study, as I have incorporated PCA as part of a multistep process to examine neighborhood change (Figure 7).

Figure 7: Diagram of Process to Create Neighborhood Typologies

I combine the results from the principal components analysis with cluster analysis, a method used by several researchers to create neighborhood typologies (Hanlon 2009; Owens 2012;
Vicino et al. 2011) as reviewed by Murdie and Logan (2014). First, factor analysis was applied to census tract level data to determine the primary dimensions of neighborhood change. Then, cluster analysis utilizes these dimensions to create a typology of neighborhoods. This information is used to characterize how prospering and struggling neighborhoods are spatially distributed in the region, and how this distribution has changed over space and time.

Factor analysis in the form of principal components analysis (PCA) is a data reduction technique well-suited to identifying the key dimensions in a set of interrelated variables (Fodor 2002; Murdie and Logan 2014; Reibel 2011). I incorporate this type of factor analysis to reduce a larger set of related measures of social vulnerability into a smaller set of uncorrelated variables, called 'principle components', that I can then use to identify patterns in these social vulnerability indicators. This method addresses "…problems of multicollinearity and reveal[s] structural relationships among neighborhood variables" (Reibel 2011, p. 309).

I use secondary data available from GeoLytics and the U.S. Census, including 1990 and 2000 censuses normalized by 2010 geographic boundaries (CensusCD 1990 in 2010 Boundaries and CensusCD 2000 in 2010 Boundaries available from GeoLytics), plus data from the 2010 to 2014 American Community Survey (ACS) 5-year estimates. After an analysis of the margin of error for the 2010-2014 ACS data revealed that the coefficient of variation exceeded the U.S. Census Bureau's recommended 30 percent (Mesenbourg et al., 2013), the decision was made to use census tract as the unit of analysis. This decision was supported by findings from Ash et al. (2013) and Boyce et al. (2014 and 2016) that within census tract exposure variation was not a substantial component of overall environmental inequality. Census tracts are designed by the 

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6 Coefficient of variation is a measure of dispersion calculated by dividing the standard deviation of an
U.S. Census to represent relatively stable, locally recognizable, spatially delimited residential settlements of homogenous populations of 1,500–8,000 people (U.S. Census 2016). The geographic boundary of this analysis is the urban growth boundary for the Central Puget Sound region, as defined by the Puget Sound Regional Council (PSRC). I selected 1990 as the starting time period for my analysis for two reasons: 1) the region began a major policy shift by adopting a regional growth vision in 1990, and 2) facility-level air pollution data, through US EPA’s Toxic Release Inventory and Risk-Screening Environmental Indicators datasets, are available for this time.

For the PCA, I compiled 18 demographic, socioeconomic, and household variables (Table 1) or each of the 739 census tracts in the Central Puget Sound region, for the 1990, 2000, and 2010 time periods. Appendix A contains a list of identification numbers for each of these variables.

Table 1: List of Variables used in Principal Components Analysis, together with related studies and rationale for selection of variable.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Previous Related Studies Using Variables</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Persons over 24 with college education</td>
<td>Abel and White 2011, 2015; Boone et al. 2014</td>
<td>Education is important predictor of health; it is often inversely related to exposure to pollution.</td>
</tr>
<tr>
<td>% Unemployed</td>
<td>Delmelle 2014; Mikelbank, 2011</td>
<td>Unemployment is often a</td>
</tr>
</tbody>
</table>

estimate by its mean. It is also referred to as the relative standard error

7 The 2010 Census tracts were spatially joined to the Urban Growth Boundary shapefile available from the Puget Sound Regional Council. All Tracts identified through the spatial join as located “inside” the Urban Growth Boundary were included in the analysis, regardless of whether the tract was only partially contained within the Urban Growth Boundary. All results depicted in maps in Chapter 4 show the Census tracts clipped to the Urban Growth Boundary.
Relative wealth is an important social determinant of health.

**Median household income**

<table>
<thead>
<tr>
<th>% Below Poverty Line</th>
<th>Abel 2008, Abel and White 2011, 2015; Delmelle 2014; Hanlon 2009; Mikelbank, 2011; Morenoff &amp; Tienda, 1997; Pastor et al. 2007; Vicino et al. 2007; Vicino, 2008; Wei &amp; Knox, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poverty is an important social determinant of health.</td>
</tr>
</tbody>
</table>

**Housing**

<table>
<thead>
<tr>
<th>% Owner occupied</th>
<th>Abel and White 2011, 2015; Delmelle 2014; Hanlon 2009; Mikelbank, 2011; Morenoff &amp; Tienda, 1997; Pastor et al. 2007; Vicino et al. 2007; Vicino, 2008; Wei &amp; Knox, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Home ownership is a standard measure of wealth. Spatial price gradients also constrain a purchaser's locational opportunities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Median home value</th>
<th>Abel and White 2011, 2015; Delmelle 2014; Hanlon 2009; Mikelbank, 2011; Morenoff &amp; Tienda, 1997; Pastor et al. 2007; Vicino et al. 2007; Vicino, 2008; Wei &amp; Knox, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Housing affordability may constrain locational opportunities for low-income residents, as well as housing access.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% Single parent household with children</th>
<th>Hanlon 2009; Mikelbank 2004; Vicino et al. 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-parent households often must juggle work responsibilities and care for family members, which can affect their resilience to hazards.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% residing in Overcrowded Housing Conditions</th>
<th>Cutter et al. 2003; Murdie and Logan 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connected with decreased physical and psychological health of children and adults</td>
</tr>
</tbody>
</table>
Demographic

<table>
<thead>
<tr>
<th>% Population</th>
<th>Authors/Year</th>
<th>Race or ethnicity is often a characteristic linked to health disparity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>White alone</td>
<td>Abel 2008; Abel and White 2011, 2015</td>
<td></td>
</tr>
<tr>
<td>African American</td>
<td>Abel 2008; Abel and White 2011, 2015</td>
<td></td>
</tr>
<tr>
<td>alone</td>
<td>Hanlon 2009; Mikelbank 2004; Pastor et al. 2007; Szasz and Meuser 2000; Vicino et al. 2007; Vicino et al. 2011</td>
<td></td>
</tr>
<tr>
<td>Asian alone</td>
<td>Abel and White 2011, 2015; Hanlon 2009; Mikelbank 2004; Pastor et al. 2007; Szasz and Meuser 2000; Vicino et al. 2011</td>
<td>Race or ethnicity is often a characteristic linked to health disparity.</td>
</tr>
<tr>
<td>Latino/Hispanic(^8)</td>
<td>Hanlon 2009; Vicino et al. 2007; Vicino et al. 2011; Pastor et al. 2007; Pulido 2000; Szasz and Meuser 2000</td>
<td>Race or ethnicity is often a characteristic linked to health disparity.</td>
</tr>
<tr>
<td>Foreign Born</td>
<td>Hanlon 2009; Mikelbank 2004; Mikelbank 2011; Vicino et al. 2007; Vicino et al. 2011; Wei and Knox 2014</td>
<td>Immigrants may have cultural or language barriers that may impact their vulnerability.</td>
</tr>
<tr>
<td>Linguistically</td>
<td>EPA 2015; Pastor et al. 2007; Sadd et al. 2011; Huang and London 2012</td>
<td>Language is a social determinant of health.</td>
</tr>
</tbody>
</table>

I standardized variables as z-scores for each census tract in the same census year to control for different measurement scales and to compare changes across time; variables therefore represent a relative value compared to all other values in the region in a particular Census time period.

\(^8\)The 1990 estimates for race are not directly comparable to 2000 and 2010 estimates due to changes in race categories on the Census questionnaire. Starting in 2000, respondents were given the option to report more than one race. In addition, the question about ethnicity was moved to precede the race question. These changes may affect comparability of 1990 estimates on Hispanic/Latino ethnicity with estimates from 2000 and 2010. Despite this, researchers completing longitudinal studies have included...
A positive z-score reflects a level higher-than-regional average, while a negative score reflects a lower-than-average level. A latent variable of the Census year is included, to allow sorting and analysis of the results by each Census time frame. I used Varimax rotation with Kaiser normalization for the PCA analysis. Varimax rotation was chosen because it provides an orthogonal solution, ensuring that the resulting factors are not highly correlated with each other, which is useful in understanding the separate, but related factors impacting neighborhood change. I selected components with an eigenvalue of more than one; this is done to remove variables that do not have high explanatory value (Field 2009; Jolliffe 2002).

PCA component scores provide the data for the cluster analysis. There is generally two options to choose between when conducting cluster analysis: hierarchical or non-hierarchical. In hierarchical classification, observations are clustered (divided or merged) in a step-wise fashion; the number of clusters does not need to be determined beforehand, but rather are ‘endogenously’ decided and judged by the large break in the percentage change in the dissimilarities when the number of groups is extended or decreased. (Wei 2013, p. 18).

In non-hierarchical methods, such as k-means, a researcher must first determine the number of clusters. Each observation is sorted into clusters, a process that continues until the dissimilarity between the clusters are maximized. Following the process used by other researchers (Abel and White 2011, 2015; Mikelbank 2011; Murdie et al. 2014), I use a hierarchical method, enabling me to review the data output and determine the appropriate number of clusters. I used a minimum-distance hierarchical technique, called Ward’s method, which maximizes this variable in their analysis (Mikelbank 2011; Wei and Knox 2014).
between-group differences while minimizing within-group differences, with the objective of identifying a small number of homogenous clusters (Lattin et al. 2003; Ward 1963).

In order to determine the appropriate number of clusters to extract from the clustering analysis, I used the following two techniques: 1) analyzed the coefficients reported in the agglomeration schedule to identify stages where large difference between the coefficients emerge, suggesting that the clusters being merged are increasing in heterogeneity; and 2) analyzed the clustergram results to visualize how the members of the clusters are formed as the number of clusters increases (Schonlau 2002; Wei 2013; Wei and Knox 2014). Once I identified the appropriate number of clusters, I described the resulting clusters based on mean z-score values for the variables used in the analysis, as well as for the components extracted through the PCA analysis. Finally, I categorize each of the clusters into a neighborhood change pattern: Prospering, Transitional, and Struggling. A sequence for each neighborhood is then created that depicts its longitudinal trajectory, describing how neighborhoods with different characteristics may fluctuate among different neighborhood patterns over time. This longitudinal analysis of neighborhood typology was implemented in the TraMineR package within the R statistical software, which has been designed for plotting sequences in longitudinal data (Gabadinho et al. 2011). Resulting sequences are used to evaluate interactions between zoning and neighborhood characteristics.

3.1.2. Neighborhood Change in Regional Centers

Analysis of zoning decisions provides an opportunity to examine the processes by which metropolitan development patterns emerge and are socially produced (Maantay 2002; Wilson et

---

9 An eigenvalue of less than 1.0 explains less information than a single item would have explained.
This research focuses on two major zoning decisions at the regional level: 1) designation of Regional Growth Centers, and 2) designation of Industrial zoned lands. These zoning designations provide examples of smart growth policies that have been adopted and implemented in the region. This research focuses on these policies and their role as a potential driver of the region's land use, demographic and socioeconomic restructuring, analyzed in Section 3.1 above. The following methods describe how the pattern of regional growth centers and industrial zoning in the Central Puget Sound region is analyzed.

**Regional Growth Centers**

Spatial data for designated Regional Growth Centers were obtained from the Puget Sound Regional Council (PSRC). The composition of neighborhoods within and adjoining designated regional growth centers is analyzed over time, to evaluate changes in neighborhood characteristics that may be associated with the adoption of the regional center designation.

**Manufacturing Industrial Centers and other areas of Industrial Zoning**

Industrial zoning data for the years 1998 and 2014 was obtained from the Puget Sound Regional Council (PSRC). PSRC routinely conducts an inventory of industrial lands to evaluate the potential build out capacity of these lands (PSRC 2015). PSRC identifies two types of industrial land supply: 1) gross industrial land supply, which refers to all industrial land, and 2) net industrial land supply, which refers to a subset of gross supply that is available for future development, such as vacant land. The inventory of gross industrial land supply is used for this study, as it encapsulates lands upon which substantial industrial development is present and permitted to occur. Industrial lands were inventoried as part of the gross land supply based upon a review of each jurisdiction’s land use designations contained in their respective
Comprehensive Plans, as well as additional lands that are currently used for industrial activities. The composition of neighborhoods within and adjoining industrial lands is analyzed over time, to evaluate changes in neighborhood characteristics that may be impacted by adjacency to industrial operations.

3.2. **Riskscape of the Central Puget Sound Region**

The riskscape section of this study examines exposure trends and hazard distribution. The approach is twofold. First, I analyze exposure trends to determine the trajectory of pollution quantity and toxicity over time. I also examine the spatial patterns of pollution changes over time, coupled with neighborhood changes discussed in Section 3.1, to determine if there is inequality in the distribution of these changes. Second, I identify areas of cumulative environmental hazard, where hotspots of different air pollution hazards converge to form areas of concentrated risk. I also examine the spatial relationship to the neighborhood characteristics identified in Section 3.1 in order to determine whether there is unevenness in the regional riskscape.

### 3.2.1. Exposure Trends

The availability of longitudinal data concerning air pollution sources is limited; as a result, this study incorporates one of the only available datasets – the U.S. Environmental Protection Agency’s (EPA) Risk-Screening Environmental Indicators (RSEI) modeling program. RSEI focuses on point-source pollution emitted from large-scale industrial sources. RSEI incorporates information about multiple chemical releases from the Toxic Release Inventory (TRI) into a comparative risk characterization of different pollution sources (Abel 2008). The TRI program tracks the release of toxic chemicals; TRI facilities must report how much of each chemical is released to the environment. TRI facilities include industrial firms that are required
by the EPA to report the release of any toxic chemical into the environment. This includes facilities from certain industrial sectors, including 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. In order to meet the threshold for TRI reporting, these facilities must have 10 or more full-time employees; manufacture or process more than 25,000 pounds of listed chemicals; or use more than 10,000 pounds of any listed chemical during the calendar year. It is important to note that releases are self-reported by the industrial operators and are not regularly validated by EPA, which can impact the accuracy of the data. While the TRI information is focused on the amount of chemicals released, RSEI also incorporates the relative toxicity of the compounds released and the potential risk that this toxicity presents to neighboring populations. The resulting ‘hazard’ results from this dataset produce a unit-less indicator value that can be used to rank relative impacts (Abel and White 2015, Schmidt, 2003; US EPA 2015).

RSEI data have been increasingly used by researchers to identify potential toxic hotspots and their proximity to socially vulnerable communities (Abel and White 2011, 2015; Ash and Fetter 2004; Downey and Hawkins 2008; Morello-Frosch et al. 2001; Sadd et al. 2011, to name a few). Incorporation of RSEI into environmental justice studies responds to early criticisms of environmental justice studies that used unit-hazard coincidence methods as a proxy for exposure risk (Chakraborty et al., 2011; Brender et al., 2011). RSEI data, in contrast, integrate air dispersion modeling with spatial analysis to estimate areas and populations exposed to airborne releases of toxic substances. Brender et al. stated that

…pollution plume modeling, a method that combines data on chemical emissions and local meteorological conditions to model the environmental fate and dispersion of pollutants, can more accurately predict exposures in the ambient environment. (Brender et al., 2011, p. S49).
US EPA provides RSEI data in two forms, both of which were analyzed for this research: 1) Facility-based data that summarize TRI chemical pounds released, hazard-based results, and risk-based results for each TRI facility (also known as EasyRSEI); and 2) 810 meter square grid-cells that estimate how the chemicals spread from a particular TRI facility to the surrounding geography, and include toxicity-weighted exposure concentrations, as well as human health hazard aggregated over every release-grid cell impacted by each industrial facility (known as RSEI- Geographic Microdata or RSEI-GM) (Boyce et al. 2016; Collins et al., 2016; US EPA 2015; Zwicki et al. 2014). The grid cell data avoids the distance-based versus unit-hazard coincidence methodological issues raised by Mohai and Saha (2015).

First, the spatial location of the region’s Toxics Release Inventory (TRI) facilities reporting air pollution emissions was plotted for 1990, 2000, and 2014. Analyses of these data were then conducted to identify the spatial distribution of large-scale facility emitters located in the region, and describe how that spatial distribution has changed over time. Layered on top of this, facility-based toxic concentration results are depicted from the EasyRSEI dataset, which were then analyzed to describe the relative toxicity-weighted exposure concentrations of facilities throughout the region. Analysis of this dataset therefore provides the opportunity to examine unevenness in facility-based toxic concentration throughout the region, which can then be compared to the neighborhood characteristics of the surrounding ‘fenceline’ communities.

Next, the grid cell data were evaluated, using data from RSEI-GM; these data allow for spatial analysis of the impacts that releases from multiple facilities may have on the same area. Grid-cell data are available in aggregated and disaggregated formats, both of which were used in this study. Aggregated data were used to evaluate cumulative impacts from multiple facilities,
while disaggregated data were used to analyze the toxic concentration of each facility, at the grid cell level.

In order to analyze individual facility level emissions, I obtained disaggregated RSEI-GM data for Washington State for the years 1990, 2000, and 2014. The disaggregated data contain scores, concentrations, and toxicity-weighted concentrations for each facility (US EPA 2015). Analysis at the facility-level allows for an assessment of the distribution of facility-based exposure, which can be used to determine the degree of disproportionality or skewness that exists in the regional facility-based exposure. This approach was used by Collins et al. 2016 to examine polluter inequality. I used the same Gini coefficient calculation to evaluate the individual facility-based proportion of toxic concentration compared to the cumulative toxic concentration of facility emissions in the region (using the R ineq package (Zeileis and Kleiber 2014)):

**Equation 2: Gini Coefficient for Facility Toxic Concentration**

\[
Gini_{Facility} = \frac{1}{2n^2 \bar{y}} \sum_{i=1}^{n} \sum_{j=1}^{n} |y_i - y_j|
\]

where \(y_i\) is the distribution of facility-level toxic concentration for facility \(1 \leq i \leq n\) (Cowell 2006).

Then, I obtained RSEI-GM aggregated data for the continental United States for 5-year periods at three different time intervals, in order to average the toxicity-weighted concentrations and take into account year-to-year variability that may otherwise misrepresent the data. The time periods and intervals included: 1990-1994; 2000-2004; and 2010-2014. The aggregated data provide scores, concentrations, and toxicity-weighted concentrations summed for the chemical releases over each grid cell (US EPA 2015). For each cell in the grid system, a location 'address'
in terms of grid and \((x,y)\) coordinates is assigned based on latitude and longitude. The grid characteristics provided in the RSEI documentation were used to recreate the grid in a GIS-based system (ArcGIS version 10.3); this included completing a Northing and Easting adjustment of the latitude and longitude and adjusting the Albers Equal-Area projection to use the latitude of origin provided (23° N instead of a typical latitude of origin of 37.5° N). Once projected, the 5-year datasets were converted to a continuous layer raster dataset that contained the toxicity-weighted concentration values, averaged over each five-year period for each grid cell. The resulting raster datasets were then clipped to the boundaries of the Urban Growth Boundary of the Central Puget Sound region. At this point, I aggregated the grid cell data to census tracts, in order to compare demographic, socioeconomic, and other characteristics with exposure estimates. I converted the raster data containing the 5-year estimates to points and joined each point with its respective RSEI 810m² grid-cell. The grid-cells were intersected with census tracts and then summarized to generate an area-weighted average of the grid-cell or proportion of grid-cell concentration contained in each census tract. The grid cell concentration information was then spatially joined to the results from the neighborhood typology created in Section 3.1. Basic descriptive statistics were calculated in order to analyze the temporal relationship between neighborhood change and exposure.

I then evaluated the skewness of the toxic concentration aggregated by census tract. I calculated each census tract's proportion of estimated toxic concentration and compared this value to the cumulative estimated concentration in the region. The Gini coefficient, a measure of inequality of a distribution, was adapted to evaluate each census tract's proportion of the estimated toxic concentration, compared to the cumulative estimated concentration in the region. This calculation was used by Boyce et al. (2016) to examine issues of vertical
environmental inequality in the 50 U.S. States. The Gini coefficient was calculated for toxic concentration by means of the following formula (using the R ineq package (Zeileis and Kleiber 2014)): 

Equation 1: Gini Coefficient for Grid-Cell Toxic Concentration

\[
Gini_{\text{Census Tract}} = \frac{1}{2n^2 \overline{y}} \sum_{i=1}^{n} \sum_{j=1}^{n} |y_i - y_j|
\]

where \(y_i\) is the distribution of toxic concentration for census tract \(1 \leq i \leq n\) (Cowell 2006).

3.2.2. Cumulative Riskscape

One key criticism of GIS-based environmental justice studies is that they generally focus on only one type of hazard and, in doing so, do not effectively consider the cumulative impacts that communities may face (Chakraborty and Maantay 2012; Sadd et al. 2011; Sexton 2012). This is largely done because of lack of quality data. This study attempts to overcome this challenge by incorporating multiple datasets to examine cumulative air quality-related environmental impacts, including: 1) large-scale, facility-based hazards discussed above in Section 3.2.1, 2) ambient air toxics and environmental risk, and 3) small-scale facilities. Due to data limitations, this analysis can only be conducted for the 2010 time frame. Each dataset is described briefly, followed by an overview of the spatial analysis and statistical methods used to analyze and describe the cumulative regional riskscape.

Large-Scale Facility-Based Hazard Data

While Section 3.2.1 above focused on exposure trends, this section utilizes the 2010-2014 RSEI aggregated grid cell data in combination with other datasets described below to
assess cumulative impacts. Specifically, the area-weighted average toxic concentration values were used in this analysis.

**Ambient Air Toxics and Environmental Risk Data**

While the RSEI dataset is focused on facility-based emissions, the U.S. EPA’s 2011 National-Scale Air Toxics Assessment (NATA) enables an assessment of ambient air quality hazards and related health-risks. NATA is a screening tool developed by EPA with the intent of measuring health risks associated with inhalation of hazardous air pollutants from multiple emission sources. Analysis of NATA data enables the identification and prioritization of pollutants, emissions sources and locations for further study. NATA data are used with increasing frequency in recent academic case studies of environmental inequality (Chakraborty, 2009; Gilbert and Chakraborty, 2011; Morello-Frosch and Jesdale, 2006 Pastor et al., 2007).

Because NATA uses emissions data compiled for a single year, and because the type of emissions data has changed between different years that NATA has been prepared, the 2011 analysis is not comparable to previous NATA datasets and represents a point-in-time analysis (US EPA 2016; Pastor et al., 2005).

The process used to generate the potential health risks is depicted in Figure 8. The 2011 National Emissions Inventory (NEI) is the principal data source for the emissions and is based upon data provided by state, local, and tribal air agencies for sources in their jurisdictions and supplemented by data developed by the US EPA. NEI includes emissions estimates from point sources (e.g., large-scale manufacturing facilities), non-point sources (e.g., residential wood combustion, commercial cooking, and consumer and commercial solvents), mobile sources (e.g., including on road cars and trucks and nonroad equipment such as lawn mowers,
construction equipment, marine vessels, trains, and aircraft), biogenics, and fires in the continental United States (Chakraborty et al., 2011; Downey and Hawkins, 2008; US EPA 2016).

![Figure 8: Process used by US EPA to develop NATA Dataset (Source: US EPA 2015)](image)

The emissions information is then input into two models to estimate ambient concentrations of air toxics in census blocks across the United States. The population of each census block is used to weight the ambient concentrations of air toxics and create a population-weighted ambient concentration for each census tract. The census tract level estimated ambient concentrations are then used as inputs to a screening-level inhalation exposure model, which incorporates a variety of data including census information, human activity pattern data, ambient air quality levels, climate data, and indoor/outdoor concentration relationships to estimate a range of exposure concentrations, depending on population characteristics. This range is further filtered to identify the exposure of a hypothetical 'typical' person for a given census tract. Risks are then calculated for a range of pollutants, resulting in the development of ambient and exposure concentrations,
cancer and noncancer risks at the census tract level. The cancer and noncancer risks at the
census tract level were used in calculating cumulative hazards.

**Small-Source Air Pollution Facility Concentration Data**

Information on smaller facilities not subject to local or state permitting is not included in
analysis such as RSEI or NATA, yet in many cases these facilities can be substantial contributors
to cumulative impacts (Maantay, 2002; Sadd et al. 2014).

Because of reporting deficiencies and the lack of comprehensive data, total
cumulative impacts from all noxious land uses within a given geography
cannot be readily calculated (Maantay, 2002, p. 163).

This lack of attention to small facilities "downplays the reality of low-dose chronic exposures to
everyday contaminants" (Allacci and Madger, 2013, p. 24).

In order to address this limitation, a number of studies of environmental inequality have
started to use land use data available from regional governments or cities, combined with
‘ground-truthing’ information supplied by local residents, to locate smaller facilities, including
auto body shops, places where vehicles idle, drycleaners, waste transfer sites, etc. (Sadd et al.,
2014). This study addresses the lack of small-scale facility information available from the RSEI
and NATA datasets by incorporating information from the Puget Sound Clean Air Agency
(PSCAA) compliance data, which contains information on a range of small-scale sources.

Business operations that create or have the potential to create air pollution within the Central
Puget Sound region are regulated by PSCAA. Air pollution sources addressed under Article 5 of
the PSCAA regulations must register with PSCAA and renew registrations annually. Article 5
includes a variety of sources, including sources that are subject to federal emissions standards as
well as smaller-scale sources that contain certain equipment and facilities, such as fuel burning
equipment, spray-coating operations, gasoline loading and dispensing facilities, crushing operations, dry cleaners using perchloroethylene, to name a few (PSCAA 2015).

The registration data available as of April 2016 were provided based upon the v_RegListActive query in the PSCAA compliance database. The resulting dataset provides facility names, addresses, type of facility, and an indication of whether the source requires a Title V permit. Because emission information is not available as part of this dataset, only the relative density of small-scale uses in proximity to socially vulnerable neighborhoods is analyzed in this study. Each facility address was geocoded to latitudinal and longitudinal coordinates and mapped. Title V sources, which are large-scale facilities required to obtain an air operating permit from PSCAA under PSCAA Regulation 1, Article 7 and Chapter 173-401 WAC, were filtered out. Then, facilities with a NAICS description that included manufacturing, transportation, mining or extraction, or other industrial uses were selected for further analysis.

**Spatial Analysis and Statistical Methods to Evaluate Cumulative Riskscape**

First, at the regional level I analyzed whether there is a relationship between exposure risk and socioeconomic and demographic characteristics. Using the neighborhood typologies and exposure risk scores, correlation tests were used to answer the question: Can the type of neighborhood you live in predict exposure risk? A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric tests were conducted, and the results were comparable. Therefore, only the results from the parametric tests are reported.

Next, I explore the spatial patterns of exposure risk to assess whether these risks are spatially correlated across space to form toxic hotspots. A technique to identify hotspots of
pollution exposure and risk was adapted from methods incorporated by Liévanos (2015) in his research on air-toxic clusters in the continental U.S. Liévanos (2015) used GIS-based spatial cluster analysis to identify hotspots of lifetime cancer risks using NATA data. In this study, this approach is expanded to use spatial cluster analysis to identify hotspots of high toxic concentration from large-scale point-source air pollution facilities, health-related risks from ambient pollution sources, and concentration of small-scale pollution sources.

Specifically, measures of spatial autocorrelation (feature similarity) based on feature locations and feature values were used to identify clusters of features with hazard and risk values that are similar in magnitude. This statistical test is used in a variety of fields including economics, resource management, biogeography, political geography and demographics. It has been used frequently in GIS-based analysis of environmental inequality (Boone et al. 2014; Liévanos 2015; Zou et al. 2014).

Two different forms of Moran's I were used for this analysis: 'global' Moran's I and 'local' Moran's I. First, a 'global' Moran's I was used to measure the broad regional tendency for values to cluster closely together in space with more similar values than would be expected if the data were drawn from a random distribution. In this measure of spatial clustering, the focus is on detecting and identifying spatial patterns in the study area. The test

\[ \text{Global Moran's I} = \frac{\sum (x_i - \mu)(x_j - \mu) W_{ij}}{\sum (x_i - \mu)^2} \]

\( \text{where } x_i \) is the value of the feature at location \( i \), \( \mu \) is the mean value, and \( W_{ij} \) is the spatial weight between locations \( i \) and \( j \).

To calculate the global Moran's I, row-standardized, a Euclidean inverse-weighted, one nearest-neighbor minimum spatial weights matrix was generated in ArcGIS 10.3 for each of the following datasets: 1) RSEI-GM 2010-2014 data for toxic concentration, 2) 2011 NATA data
for both cancer and non-cancer risks, and 3) the small-scale pollution sources. The resulting z-
score from the test is used to indicate the likelihood that the observed pattern is not simply due
to chance. A Moran’s I greater than 0 denotes a clustered pattern, values less than 0 denote a
dispersed pattern, and values at or approaching 0 suggest a random spatial pattern.

Next, local indicators of spatial association were assessed using Anselin's Moran's I (local
Moran). Unlike the global statistic, local Moran identifies where spatial clusters exist (Mitchell
2005). In this case, local Moran's is used to determine which census tracts are most similar and
dissimilar in terms of the identified measures of environmental inequality. Similar to the global
Moran's I, the spatial weights matrix informed the local Moran's I calculation to test the
randomization hypothesis, that “the likelihood that a feature having values similar to its
neighbors is not due to chance” (Mitchell p. 164). The local Moran's I calculation is a weighted
sum of neighboring tracts' differences from the mean scaled by the current tract's difference
from the mean:

\[ I_i = z_i \sum_j w_{ij}z_j \]

where \( z_i \) is track i's difference from the mean and \( w_{ij} \) is the weight given to neighboring track
j's difference from the mean. Note that \( w_{ii} = 0 \). (Anselin 1995 as referenced in Liévanos 2015,
p. 54).

A False Discovery Rate (FDR) correction, applied to control for multiple test and spatial
dependency issues, estimates the number of false positives for a given confidence level and
adjusts the critical p-value accordingly (ESRI 2016), removing the weakest statistically significant
p-values, based on an ordered list.
The output of the local Moran's I includes a z-score, which is used to generate a Moran scatterplot, with the following quadrants: (1) “high–high” clusters, where high values (such as high toxic concentration) are surrounded by other high-value tracts, (2) “low–low” clusters, where low values (such as low toxic concentration) are surrounded by other low-value tracts, (3) “high–low” outliers, where high values (such as high toxic concentration) are surrounded by low value tracts, and (4) low–high” outliers, where low values (such as low toxic concentration) are surrounded by high-value tracts. Tracts not found to have substantial spatial association with their neighboring tracts are deemed not significant. The resulting high–high clusters, which represent the hot spots from the Moran typology, were used in correlation tests to examine whether there is a relationship between hotspots of exposure risk and socioeconomic and demographic characteristics. Similar to the region-wide analysis, a test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric tests were conducted, and the results were comparable. Therefore, only the results from the parametric tests are reported.

In addition, the high-high clusters for multiple environmental hazards (RSEI Toxic Concentration, NATA cancer and non-cancer risk scores, and Small Sources) were combined to identify areas that were simultaneously identified as hotspots for air pollution risk from point, ambient, and small source emissions. Additional correlation tests, as described previously, were performed to assess the relationship between hotspots of exposure risk and socioeconomic and demographic characteristics.

3.3. Air Quality-Related Healthscape in the Central Puget Sound Region

Finally, health data are layered on top of the comparison of neighborhood characteristics and measures of environmental inequality to assess the extent to which poor air-
quality-related health outcomes are associated with the environmental riskscape. The approach is twofold. First, I analyze trends in asthma hospitalization rates to determine the trajectory of this health outcome over time. I also examine the spatial patterns of change over time, coupled with the neighborhood changes discussed in Section 3.1, to determine if there is inequality in the distribution of these changes. Second, I conduct correlation tests to assess the relationship between asthma hospitalization rates and socioeconomic and environmental exposure factors previously addressed in Sections 3.1 and 3.2, respectively.

3.3.1. Health Outcome Trends

I acquired Comprehensive Hospital Abstract Reporting System (CHARS) data from the Washington State Department of Health for the years 1990, 2000, and 2014. CHARS contains coded hospital inpatient discharge information derived from hospital billing systems and provides information on age, sex, zip code and billed charges of patients, as well as the codes for their diagnoses and procedures (WA Department of Health 2016). For this study, asthma hospitalization rates were used as the health outcome of interest, as a variety of studies have documented a relationship between asthma hospitalization and socioeconomic (Bime 2016; Claudio et al, 1999) and environmental exposure (Bime 2016; Zheng et al. 2015) factors.

The data were filtered to include patients residing within zip codes located in the Central Puget Sound region. The data were then filtered for ICP-9 diagnosis codes associated with asthma related visits (codes starting with 493). The data were averaged for each Zip code, by dividing by the population estimate provided in the 1990, 2000, and 2014 Gazetteer Files provided by the US Census. These results provide a rate of hospitalization per person. To merge the Zip code result into a census tract, which allows for comparison with the neighborhood typology information, the Zip code data were spatially joined to a census tract.
shapefile and an area-weighted average was calculated (Tam Park 2014; Hibbert et al 2009). Since 1990 zip code boundaries are not available, 2000 Zip Code tabulation areas provided by the US Census were used for this analysis. Then, the census tract data were summarized and joined into the census tract shapefile. Basic descriptive statistics were calculated in order to analyze the temporal changes in asthma hospitalization rates.

### 3.3.2. Relationship between Health Outcomes and Socioeconomic and Environmental Exposure

Correlation tests were run to assess the relationship between socioeconomic and environmental exposure factors and asthma hospitalization rates. A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametrics tests were conducted, and the results were comparable. Therefore, only the results from the parametric tests are reported.

The RSEI, NATA, and Small Source Facility Concentration variables are a continuous level of measurement and, as a result, a Pearson correlation was used to evaluate the nature of the relationship between these variables and asthma hospitalization rates. Then, a one-way ANOVA test was performed to examine the relationship between neighborhood Cluster types and asthma. The Cluster type was coded as a categorical variable, with each Cluster type analyzed to determine if there were statistically significant differences in asthma hospitalization rates among the three cluster types. The statistical significance of all tests was assessed at the 95 percent confidence interval.
Chapter 4. Results

This section reviews the key results from this analysis. Section 4.1 describes the policyscape, including the regional neighborhood typology created from the Principal Component Analysis and Hierarchical Clustering, as well as the focused review of neighborhood change in regional centers. Section 4.2 describes exposure trends and the cumulative air pollution riskscape, including a statistical analysis to identify whether neighborhood characteristics act as predictors of environmental inequality. Finally, health outcomes are evaluated in Section 4.3.

4.1. Policyscape

Development patterns influence quality of life and access to opportunity in many ways, including housing affordability and quality, access to employment and services, quality of schools, public transportation, levels of physical activity, and environmental quality. Planning decisions have an important role in shaping these development patterns. As a result, equitable development is concerned with ensuring that residents of all incomes, races, and ethnicities benefit from decisions that shape the places where they live (EPA 2016a). This section evaluates how the region's socioeconomic and demographic characteristics have changed over time in order to draw conclusions about the socio-spatial outcomes of regional policy decisions. To characterize the outcomes of the Central Puget Sound's regional growth planning efforts, I analyze the results from the regional neighborhood typology created from the Census Data for the years 1990 through 2010. First, overall patterns of regional neighborhood change are examined. Then, patterns of regional change within designated regional centers discussed in Section 3.1.2 are analyzed. A detailed analysis of the results from the principal component
analysis (PCA) and clustering results is included in Appendix B and C, respectively. This section, in contrast, focuses on key results from these analyses.

4.1.1. **Longitudinal Analysis of Regional Neighborhood Change**

The cluster typology was derived from a three-factor PCA solution that revealed socioeconomic status, racial polarization, and non-traditional household as the underlying dimensions of the 18 different variables used to examine neighborhood characteristics in the Central Puget Sound region (Table 2). The three-factor solution explained over 67 percent of the total variance. Component 1, which highlights differences in socioeconomic status, explains over 28 percent of the variance. Component 2, which highlights differences in racial and ethnicity mixing or segregation, explains an additional 26 percent of the variance. Component 3, which highlights differences in household structure, explains a final 13 percent of the variance.
Table 2: Results of Principal Components Analysis, all years (1990 - 2010)

<table>
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<th>Category and Variable Name</th>
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<td>Socioeconomic Status</td>
<td>Racial/Ethnic Polarization</td>
<td>Non-Traditional Household</td>
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</tr>
<tr>
<td>Owner-occupied</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percent Variance 28.3% 26.0% 13.3%
Cumulative Variance 28.3% 54.3% 67.6%

Notes: Loadings -0.50 to +0.50 not shown.
Varimax rotation with Kaiser normalization.

The results of the cluster analysis yielded groupings of census tracts with similar values on the three factors derived from the PCA (Table 3). Figure 9 through Figure 11 display the temporal cross-section of a 9-cluster characterization of the region's neighborhood changing demographics and socioeconomic status. I have arranged the legend for the cluster analysis to use cooler colors (i.e. blue and green) to represent clusters with relatively higher socioeconomic
status and warmer colors (i.e. reds and browns) to represent clusters with relatively lower socioeconomic status. The pattern reveals a spatial divide across the region: clusters exhibiting higher relative socioeconomic status are located in a pattern radiating out from the Seattle-Bellevue core.

Generally, the cluster exhibiting the highest relative socioeconomic status, Old City Establishment, contains prime waterfront neighborhoods and suburban communities located on the eastside of Lake Washington. These ‘Gentry’ clusters are relatively more concentrated and centralized near the core of the region compared to those with relatively lower socioeconomic status, consistent with findings from Dwyer (2010), who included Seattle in his analysis of changes in regional metropolitan patterns in the United States. Adjoining these areas are Middle Class Suburbs, Family Suburban Homeowners, and Emerging Middle Class. These areas also have relatively high socioeconomic status.

In contrast, areas located further from the core, to the north and south, exhibited relatively lower socioeconomic status. The clusters that exhibit the lowest indicators of socioeconomic status are located southeast of the Seattle core, near military bases, and along major transportation corridors in the region. Therefore, unlike the majority of regions in the United States that exhibit a concentric zone model, in which the affluent reside on the periphery of the urban area (Dwyer 2010), the region exhibits a patchwork pattern of class and racial segregation.

The analysis revealed that Pugetopolis neighborhoods across the region were spatially divided by demographic and socioeconomic characteristics. The region’s socioeconomic equality diverged from 1990 to 2010.
Figure 9: Central Puget Sound Region Neighborhood Typology, 1990
Figure 10: Central Puget Sound Region Neighborhood Typology, 2000
Figure 11: Central Puget Sound Region Neighborhood Typology, 2010
<table>
<thead>
<tr>
<th><strong>Gentry Clusters</strong></th>
</tr>
</thead>
</table>
| **Old City Establishment:** *Centrally located near central and edge cities, this cluster is characterized by high incomes and wealth, including high housing values, ownership rates, and college and professional employment.*  
Demographics: Above average rate of white population; lowest rate of African American population; above average rate of Asian population; lowest rate of Latino population; below average rate of linguistically isolated population; slightly above average rate of foreign born  
Social status: Second highest rate of college graduates, substantially above regional average; above average rate of professional workers; highest household income, substantially above regional average; lowest poverty rate, substantially below regional average; highest rate of home ownership; lowest unemployment rate  
Household structure: Lowest rate of young households (24-35 years); below average rate of non-family households; lowest rate of single-parent households; lowest rate of overcrowded housing  
Housing Costs: Highest rental cost, substantially above regional cost; highest house value, substantially higher than regional average |
| **Middle Class Suburbs:** *This cluster is generally located in accessible urban and suburban areas and residents have average socioeconomic status and stable housing values. Less racial mixing than other clusters.*  
Demographics: Second highest rate of white population; below average rate of African American population; below average rate of Asian population; below average rate of Latino population; below average rate of linguistically isolated population; below average rate of foreign born  
Social status: Above average rate of college graduates; above average rate of professional workers; average household income; below average poverty rate; slightly below rate of home ownership; below average unemployment rate  
Household structure: Second highest rate of young households (24-35 years), slightly above regional average; second highest rate of non-family households; below average rate of single-parent households; below average rate of overcrowded housing  
Housing Costs: Average rental cost; above regional average house value |
**Suburban Clusters**

**Family Suburban Homeowners:** This cluster is generally found in the outer suburbs or exurbs, and residents generally have traditional family households and have higher home ownership rates and household incomes than regional average. Less racial mixing than other areas in the region.

- **Demographics:** Above average rate of white population; below average rate of African American population; slightly below average rate of Asian population; slightly below average rate of Latino population; below average rate of linguistically isolated population; below average rate of foreign born
- **Social status:** Average rate of college graduates; slightly below average rate of professional workers; above average household income; below average poverty rate; second highest rate of home ownership; below average unemployment rate
- **Household structure:** Slightly below average rate of young households (24-35 years); lowest rate of non-family households; below average rate of single-parent households; below average rate of overcrowded housing
- **Housing Costs:** Slightly above average rental cost; slightly below regional average house value

**Emerging Middle Class/Asian Influx Suburbs:** Exurban areas that have average education, incomes, and poverty and unemployment status. Housing values are average, and ownership rates are less than the regional average. More racial mixing than other clusters.

- **Demographics:** Below average rate of white population; above average rate of African American population; second highest rate of Asian population, substantially above regional average; above average rate of Latino population; above average rate of linguistically isolated population; above average rate of foreign born, substantially above regional average;
- **Social status:** Slightly above average rate of college graduates; above average rate of professional workers; slightly below average household income; slightly above average poverty rate; below average home ownership; slightly below average unemployment rate
- **Household structure:** Slightly above average rate of young households (24-35 years); slightly above average rate of non-family households; average rate of single-parent households; above average rate of overcrowded housing
- **Housing Costs:** Average rental cost; average house value
### Creative Class

**Young, Single, Educated and Mobile Renters:** *This cluster exhibits many of the characteristics of new technology workers. This cluster is concentrated in inner-city areas, near city amenities, and has high education levels, high income, are young, and generally single, and choose to rent.*

- **Demographics:** Average rate of white population; average rate of African American population; average rate of Asian population; slightly below average rate of Latino population; average rate of linguistically isolated population; average rate of foreign born
- **Social status:** Highest rate of college graduates, substantially above regional average; below average household income; above average poverty rate; lowest rate of home ownership; below average unemployment rate
- **Household structure:** Highest rate of young households (24-35 years), substantially above regional average; highest rate of non-family households, substantially higher than regional average; below average rate of single-parent households; below average rate of overcrowded housing
- **Housing Costs:** Slightly below average rental cost; above regional average house value

### Working Class

**White Working Class Suburbs:** *This cluster is generally found in outer suburbs, where racial mixing has not occurred and residents exhibit lower relative rates of employment in professional fields, college education levels, and income. Housing values are depressed, but the area exhibits higher than average rates of home ownership.*

- **Demographics:** Highest rate of white population; below average rate of African American population; lowest rate of Asian population; slightly below average rate of Latino population; lowest rate of linguistically isolated population; lowest rate of foreign born, substantially below regional average
- **Social status:** Below average rate of college graduates, substantially below regional average; lowest rate of professional workers; slightly below average household income; slightly below average poverty rate; above average rate of home ownership; average unemployment rate
- **Household structure:** Slightly below average rate of young households (24-35 years); below average rate of non-family households; average rate of single-parent households; below average rate of overcrowded housing
- **Housing Costs:** Below average rental cost; below average regional house value
Struggling Working Class Suburbs: *Exurban suburbs that have less education, low incomes, and high poverty and unemployment status. Housing values are low, and ownership rates are less than the regional average. Less racial mixing than other clusters.*

Demographics: Average rate of white population; above average rate of African American population; below average rate of Asian population; second highest rate of Latino population; average rate of linguistically isolated population; below average rate of foreign born

Social status: Lowest rate of college graduates, substantially below regional average; below average rate of professional workers; third lowest household income, substantially below regional average; above average poverty rate; below average home ownership; second highest unemployment rate

Household structure: Slightly above average rate of young households (24-35 years); slightly above average rate of non-family households; second highest rate of single-parent households; above average rate of overcrowded housing

Housing Costs: Second lowest rental cost; lowest house value, substantially below regional value

<table>
<thead>
<tr>
<th>Vulnerable Clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower-Income and Non-Traditional Household Suburbs:</strong> <em>This cluster is located in inner suburbs or along corridors and exhibits a higher than average rate of racial/ethnic mixing, with an emerging Latino population. Residents within this cluster are also struggling economically, with high poverty, low income levels, and low levels of home ownership.</em></td>
</tr>
</tbody>
</table>

Demographics: Below average rate of white population, substantially below regional average; second highest rate of African American population, substantially above regional average; below average rate of Asian population; highest rate of Latino population, substantially above regional average; second highest rate of linguistically isolated population; second highest rate of foreign born, substantially above regional average; average rate of professional workers; second lowest household income, substantially below regional average; second highest rate of poverty, substantially above regional average; second lowest rate of home ownership; above average unemployment rate

Social status: Below average rate of college graduates, substantially below regional average; average rate of professional workers; second lowest household income, substantially below regional average; second highest rate of poverty, substantially above regional average; second lowest rate of home ownership; above average unemployment rate

Household structure: Slightly above average rate of young households (24-35 years); slightly above average rate of non-family households; highest rate of single-parent households; second highest rate of overcrowded housing

Housing Costs: Below average rental cost; second lowest house value, substantially below regional value
**Disadvantaged Racial/Ethnic Enclave:** This cluster exhibits the region's highest concentrations of racial minorities, as well as foreign born and linguistically isolated. Residents within this cluster are also struggling economically, with high poverty and unemployment rates and low income levels.

- **Demographics:** Lowest rate of white population, substantially below regional average; highest rate of African American population, substantially higher than regional average; highest rate of Asian population, substantially above regional average; above average rate of Latino population; highest rate of linguistically isolated population, substantially above regional average; highest rate of foreign born, substantially above regional average.

- **Social status:** Below average rate of college graduates, substantially below regional average; average rate of professional workers; lowest household income, substantially below regional average; highest rate of poverty, substantially above regional average; below average home ownership; highest unemployment rate, substantially higher than regional average.

- **Household structure:** Average rate of young households (24-35 years); average rate of non-family households; above average rate of single-parent households; highest rate of overcrowded housing, substantially above regional average.

- **Housing Costs:** Lowest rental cost, substantially below regional cost; below average regional house value, substantially below regional value.

In order to classify the trajectory of neighborhood changes, the clusters were further simplified into three different clusters based upon their socioeconomic and demographic characteristics: 1) Prospering, which includes the following three clusters on the 'cool' end of the cluster spectrum: Old City Establishment, Middle Class Suburbs, and Family Suburban Homeowners; 2) Transitional clusters, which includes the following three clusters spanning the middle of the cluster spectrum: Emerging Middle Class/Asian Influx Suburbs, Young, Single, Educated and Mobile Renters, and White Working Class Suburbs; and 3) Struggling clusters, which includes three clusters on the 'warm' end of the cluster spectrum: Struggling Working Class Suburbs, Low-Income, Non-Traditional Household Suburbs, and Disadvantaged Racial/Ethnic Enclave. Prospering clusters are the most prevalent and contain the largest proportion of residents (Table 4), but the trends reveal an overall decline in the number of census tracts falling within Prospering clusters (from 49.4 to 42.6 percent of census tracts) and proportion of residents (from 52.5 to 42.2 percent). The Prospering clusters are replaced over time by Struggling clusters, which have grown in both the number of census tracts (from 14.2 to
20.4 percent of census tracts) as well as the proportion of residents (from 15.5 to 23.2 percent) within the study time period.

Table 4: Census tract count and population for Neighborhood Typology Trajectory, 1990 through 2010

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>Valid N #/(%)</th>
<th>Population #/(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>365</td>
<td>(49.4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transitional</td>
<td>269</td>
<td>(36.4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Struggling</td>
<td>105</td>
<td>(14.2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional Total</td>
<td>739</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 12 depicts the transition between cluster types that occurs within the region over time, with the left-column depicting cluster type designation in 1990 and the right-hand column depicting cluster type designation in 2010. The y-axis represents the percentage of the transition sequence as a proportion of the total. The largest proportion of clusters is stable over time, remaining within the same cluster type. This finding of overall stability is consistent with the findings of Wei and Knox (2014), Delmelle (2015), and Chapple (2014). However, a substantial number of clusters show relative downgrading from Prospering to Transitional cluster types and from Transitional cluster types to Struggling cluster types. Less frequent are transitions that include relative upgrading, with clusters changing from Transitional to Prospering cluster types. These patterns are reflective of the region's growing inequality, an observation shared by other researchers examining processes of neighborhood change, including Wei and Knox (2014);

---

10 Nine Census tracts did not have sufficient information to classify in 2010.
Delmelle (2015); and Galster et al. (2008).

Figure 12: 10 most frequent longitudinal cluster transition sequences.

Figure 13 through Figure 15 depict the spatial location and change in these cluster types over time, revealing that the growth in Struggling clusters has largely occurred along transportation corridors south of the Seattle core. Areas of relative upgrading have occurred in portions of Seattle and outlying suburbs.
Figure 13: Central Puget Sound Region Neighborhood Typology Trajectory, 1990
2000 Central Puget Sound Region Neighborhood Typology

- Major Roadways
- Regional Urban Growth Boundary
- Prospering Cluster Tracts (n=305, 41.3%)
- Transitional Census Tracts (n=295, 39.9%)
- Struggling Census Tracts (n=139, 18.8%)

Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet
Data Sources: GeoLytics, Puget Sound Regional Council, ESRI
Prepared by: Stacy Clauson
Date: May 16, 2016

Figure 14: Central Puget Sound Region Neighborhood Typology Trajectory, 2000
Figure 15: Central Puget Sound Region Neighborhood Typology Trajectory, 2010
Table 5 contains a breakdown of the demographic characteristics of these cluster types over time. The characteristics reveal sharp differences between the three different cluster types. One key example concerns racial and ethnic diversity. Overall, while the region has increasingly become more racially and ethnically diverse, these changes have not been occurring evenly. Prospering clusters are predominately white and contain a higher proportion of white residents than other cluster types in all years. Further, the white population has declined the least within the Prospering clusters (from 89.5 to 74.2 percent) (Table 5a). In contrast, Struggling clusters have above average proportion of minorities, a trend that has been increasing over time. By 2010, Struggling cluster types are no longer majority white (51.4 percent are non-white). This is largely the result of a dramatic increase in the Latino population, which has grown from 4.9 to 17.4 percent of the population within this neighborhood type (Table 5b). The region’s proportion of foreign born residents has also increased (from 7.5 to 16.3 percent), but similarly both the largest proportion and the largest increase over time (from 12.3 to 23.8 percent) has occurred within Struggling clusters (Table 5c). A similar situation occurs for linguistically isolated residents, which has grown from 5.9 to 10.0 percent in Struggling clusters (Table 5c).

Table 5: Demographic characteristics of Neighborhood Typology Trajectory, 1990 through 2010

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% White Alone</th>
<th>% African American Alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>89.5%</td>
<td>82.9%</td>
</tr>
<tr>
<td>Transitional</td>
<td>88.5%</td>
<td>78.7%</td>
</tr>
<tr>
<td>Struggling</td>
<td>64.5%</td>
<td>56.7%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>85.6%</td>
<td>76.3%</td>
</tr>
</tbody>
</table>
Table 5b

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% Asian Alone 1990</th>
<th>% Asian Alone 2000</th>
<th>% Asian Alone 2010</th>
<th>% Latino 1990</th>
<th>% Latino 2000</th>
<th>% Latino 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>5.0%</td>
<td>7.2%</td>
<td>11.2%</td>
<td>2.4%</td>
<td>3.5%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Transitional</td>
<td>4.4%</td>
<td>7.2%</td>
<td>10.4%</td>
<td>2.5%</td>
<td>4.7%</td>
<td>7.9%</td>
</tr>
<tr>
<td>Struggling</td>
<td>13.1%</td>
<td>12.6%</td>
<td>13.3%</td>
<td>4.9%</td>
<td>10.0%</td>
<td>17.4%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>5.9%</td>
<td>8.2%</td>
<td>11.2%</td>
<td>2.8%</td>
<td>5.2%</td>
<td>9.2%</td>
</tr>
</tbody>
</table>

Table 5c

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% Foreign Born 1990</th>
<th>% Foreign Born 2000</th>
<th>% Foreign Born 2010</th>
<th>% Linguistically Isolated 1990</th>
<th>% Linguistically Isolated 2000</th>
<th>% Linguistically Isolated 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>7.1%</td>
<td>10.7%</td>
<td>14.7%</td>
<td>1.2%</td>
<td>2.2%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Transitional</td>
<td>6.1%</td>
<td>10.8%</td>
<td>14.3%</td>
<td>1.4%</td>
<td>3.0%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Struggling</td>
<td>12.3%</td>
<td>18.5%</td>
<td>23.8%</td>
<td>5.9%</td>
<td>8.6%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>7.5%</td>
<td>12.2%</td>
<td>16.3%</td>
<td>2.0%</td>
<td>3.7%</td>
<td>4.6%</td>
</tr>
</tbody>
</table>

Table 6 contains a breakdown of the socioeconomic characteristics of these cluster types over time. Again, the characteristics reveal divides between the three different cluster types and the gap between clusters appears to be widening over time. Struggling clusters have the highest poverty rate for all years, over double the poverty rate of either Prospering or Transitional clusters (24.4 percent for Struggling in 2010, compared to 11.2 and 7.0 for Transitional and Prospering, respectively) (Table 6c). Residents of Struggling clusters were also more likely to be unemployed (12.4 percent for Struggling in 2010, compared to 8.2 and 6.5 for Transitional and Prospering, respectively). Both the proportion of residents in poverty and unemployed has grown region-wide between 1990 and 2010. Residents of Struggling clusters also earn substantially less than their counterparts in Transitional and Prospering clusters (Table 6b). In
2010, residents of Struggling clusters earned less than one-half the income as residents in
Prospering clusters. The wage gap between these clusters has been increasing in time, from
$27,461 in 1990 to $38,868 in 2010. Educational attainment is also substantially different (Table
6a). Almost half (49.3 percent) of residents aged 25 had a college degree in Prospering clusters,
but only 19 percent of residents in Struggling clusters had this level of educational attainment.
The educational attainment gap between Prospering and Struggling clusters was 18.7 percent in
1990, but grew to 30.0 percent in 2010.

Table 6: Socioeconomic characteristics of Neighborhood Typology Trajectory, 1990 through 2010

<table>
<thead>
<tr>
<th>Table 6a</th>
<th>Cluster Type</th>
<th>% Age 25-34</th>
<th>% College Graduates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>18.7%</td>
<td>13.4%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Transitional</td>
<td>19.8%</td>
<td>17.1%</td>
<td>8.6%</td>
</tr>
<tr>
<td>Struggling</td>
<td>21.1%</td>
<td>18.1%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>19.5%</td>
<td>15.8%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6b</th>
<th>Cluster Type</th>
<th>% Professional/Managerial Occupations</th>
<th>Median Household Income (2000 Dollar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>7.9%</td>
<td>12.0%</td>
<td>9.7%</td>
</tr>
<tr>
<td>Transitional</td>
<td>6.2%</td>
<td>10.2%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Struggling</td>
<td>6.7%</td>
<td>9.1%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>7.1%</td>
<td>10.8%</td>
<td>8.3%</td>
</tr>
</tbody>
</table>
Finally, Table 7 contains a breakdown of the housing characteristics of these cluster types over time. This final set of characteristics continues to show differences between the three clusters. Struggling clusters consistently have the highest proportion of non-traditional family characteristics, including non-related persons living in households (9.3 percent in 2010, compared to a regional average of 8.2 percent), single-parent households (22.5 percent, compared to a regional average of 13 percent), and overcrowded housing conditions (6.4 percent, compared to a regional average of 2.9 percent) (Tables 7a and 7b).

Prospering clusters, in contrast, exhibit more traditional family characteristics, with lower proportions of non-related persons living in households (7.3 percent in 2010, compared to a regional average of 8.2 percent), single-parent households (8.8 percent, compared to a regional average of 13 percent), and overcrowded housing conditions (1.4 percent, compared to a regional average of 2.9 percent). While a majority of residents in Prospering clusters own their homes (73 percent in 2010), only a minority of residents in Struggling clusters are homeowners (38.7 percent) (Table 7c). Homes values are substantially higher in Prospering versus Struggling clusters (values are two times higher in 2010), and the gap between housing values grew from $103,626 in 1990 to $165,875 in 2010. Interestingly, the proportion of owner-occupied housing

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% Poverty Status</th>
<th>% Unemployed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>5.0%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Transitional</td>
<td>8.8%</td>
<td>8.5%</td>
</tr>
<tr>
<td>Struggling</td>
<td>22.4%</td>
<td>18.9%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>8.9%</td>
<td>8.9%</td>
</tr>
</tbody>
</table>
units has seen a reversal over time, with the proportion growing substantially in Prospering clusters, but declining over time in Struggling clusters.

Table 7: Housing characteristics of Neighborhood Typology Trajectory, 1990 through 2010

Table 7a

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% 2+ Person Non-Family Household</th>
<th>% Single Parent Headed Household</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>15.0%</td>
<td>6.3%</td>
</tr>
<tr>
<td>Transitional</td>
<td>17.2%</td>
<td>9.3%</td>
</tr>
<tr>
<td>Struggling</td>
<td>18.6%</td>
<td>8.4%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>16.3%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

Table 7b

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% Overcrowded Housing</th>
<th>Median Gross Rent (2000 Dollar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>2.1%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Transitional</td>
<td>3.3%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Struggling</td>
<td>8.3%</td>
<td>10.6%</td>
</tr>
<tr>
<td>Regional Average</td>
<td>3.4%</td>
<td>4.8%</td>
</tr>
</tbody>
</table>
### Table 7c

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>% Median Housing Value (2000 Dollar)</th>
<th>% Owner-Occupied Housing Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>$200,822</td>
<td>$266,289</td>
</tr>
<tr>
<td>Transitional</td>
<td>$142,188</td>
<td>$193,255</td>
</tr>
<tr>
<td>Struggling</td>
<td>$97,196</td>
<td>$150,457</td>
</tr>
<tr>
<td>Regional Average</td>
<td>$164,756</td>
<td>$215,347</td>
</tr>
</tbody>
</table>

#### 4.1.2. Descriptive Longitudinal Analysis of Neighborhood Change in Regional Centers

In this section, I explore the role of regional centers, both regional growth centers and manufacturing industrial centers, in contributing to the pattern of regional socio-spatial inequality observed in Section 4.1.1.

**Regional Growth Centers**

An EPA study of residential development patterns in metropolitan regions indicates that the region is in the top 10 large metropolitan regions with the greatest share of infill home construction (EPA 2012). PSRC's monitoring of regional growth centers has indicated that the centers are accommodating more of the residential growth in the region over time (PSRC 2016). Yet, analysis of neighborhood change in regional growth centers reveals a mix of different outcomes resulting from this focused growth.

The urban growth centers exhibit a trend toward increasing homogeneity, exhibiting less diversity in cluster types within the center over time (Figure 16). Of the 27 regional clusters examined, only 6 show signs of growing diversity in cluster types (Lynnwood, Puyallup...
Downtown, Puyallup South Hill, Seattle Northgate, Seattle University and Tukwila as shown in Figure 16). The majority of regional growth centers (15 out of 27) show relative downgrading over time\textsuperscript{11}. Downgrading in many of these growth centers, such as Federal Way, Kent, Lakewood, SeaTac and Tukwila, saw a substantial conversion of Prospering and Transitional clusters to Struggling clusters. This pattern is consistent with regional neighborhood changes, in which Struggling clusters have grown in number along major transportation corridors, particularly in areas south of Seattle.

Five of the 27 regional growth centers show relative upgrading, including Burien, Kirkland Totem Lake, Seattle Downtown, Seattle First Hill, and Seattle South Lake Union. Of these five, two clusters in Seattle (Seattle Downtown and Seattle First Hill/Capitol Hill) have been identified by PSRC as two of the top three fastest growing regional growth centers in the region, adding more housing units than other clusters (PSRC 2016). In these two centers, the proportion of Prospering and Transitional area grew, while Struggling areas shrank. This finding reveals that a segregated pattern of post-siting demographic change occurred in areas with high redevelopment pressure. This is consistent with findings by Morrill (2011) and Abel and White (2015) who noted that gentrification pressures in certain areas of Seattle were displacing minority and poor residents. These trends (increasing homogeneity, downgrading in centers south of Seattle, and gentrification processes) raise concerns about whether urban growth centers are providing areas of economic diversity, a key element of the \textit{Vision 2040} regional growth strategy and in Smart Growth planning.

\textsuperscript{11} For the purposes of this analysis, upgrading was classified to include centers that increased the proportion of Transitional or Prospering neighborhood types after center designation. The reverse is true for downgrading, where the proportion of Transitional or Struggling increased after center designation.
Figure 16: Comparison of urban growth center composition by neighborhood cluster type before and after designation.

**Manufacturing Industrial Centers**

The region’s industrial zoning has remained relatively stable over time (PSRC 2013). Within regionally designated Manufacturing Industrial Centers (MICs), changes have been mostly in the form of infill zoning within the MIC boundary, or minor loss of industrial zoning outside of the MIC boundary.
Analysis of neighborhood change in MICs reveals varied patterns (Figure 17).\textsuperscript{12} The MICs are ordered by whether there was a trend of upgrading or downgrading over time. Three of the eight MICs show relative upgrading (Duwamish, Port of Tacoma, and Bremerton). Of these, Duwamish and Port of Tacoma are adjacent to urban growth centers (Seattle Downtown and Tacoma Downtown, respectively) and, as a result, portions of these clusters may be experiencing pressure for conversion. Five show relative downgrading, (Ballard Interbay, Frederickson, Kent, North Tukwila, and Paine Field/Boeing Everett). In particular, Kent and North Tukwila show a turnaround in neighborhood composition, from predominately Prospering to either Struggling or Transitional. This is consistent with region-wide neighborhood changes, in which interior areas along major transportation corridors experienced relative downgrading.

\textsuperscript{12} It should be noted that industrial uses of the areas within MICs likely predated official designation of the MICs. Therefore, pre-designation cluster types are not analyzed for disparate siting practices.
Outside of MICs, there has been some conversion of industrial-zoned land to other land uses. As noted by PSRC (2013), "As the region grows and evolves, several cities are responding to demand for residential, office, and mixed-use development by rezoning previously industrial zoned areas" (p. 2-7). Conversion of these lands may result in displacement of existing industrial uses, shifting the patterns of the industrial landscape, as further discussed in the next section.
4.2. **Air Pollution Riskscape**

This section focuses on determining whether the location, distribution and intensity of environmental hazards in the region result in skewed riskscapes, in which some neighborhoods face disproportionately higher risks. The approach is twofold. First, I analyze exposure trends to determine the trajectory of pollution quantity and toxicity over time. I also examine the spatial patterns of pollution changes over time, coupled with the neighborhood changes discussed in Section 3.1, to determine if there is inequality in the distribution of these changes. Second, I identify areas of cumulative environmental hazard, where hotspots of different air pollution hazards converge to form areas of concentrated risk. I also examine the spatial relationship to the neighborhood characteristics identified in Section 3.1 in order to determine whether there is unequal distribution of exposure risk.

### 4.2.1. **Longitudinal Assessment of Air-Quality Environmental Hazards and Risks**

In this section, I analyze the pollution riskscape over time from two different vantages: the pollution source and the pollution receptor, in this case the communities most impacted by the pollution. This section analyzes changes in the spatial distribution of pollution sources and pollution exposure risk over time, and concludes with analysis of the communities with the greatest exposure risk from large-scale emitters.

**Pollution Sources**

Analysis of the region's large-scale point-source polluters reveals that there is substantial skewness in the distribution of pollution sources across the region. The Gini coefficient, used to evaluate the individual facility-based proportion of estimated exposure (toxic concentration) compared to the cumulative estimated exposure in the region, is above 0.90 for all years (Table
8), indicating that a few key facilities that are contributing the most toxic concentration emissions in the region. The years 1990 and 2014 show the greatest skewness in facility emissions (both have Gini Coefficients of 0.97), indicating that fewer facilities are contributing the most to the exposure risk or that the few are contributing more in these years. These findings are consistent with findings from Collins et al. (2016), who also found "extreme distributional unevenness" (p. 7), with a facility-based Gini Coefficient of 0.96 across the continental U.S..

Table 8: Gini Coefficient for TRI-facility proportion of cumulative estimated regional exposure

<table>
<thead>
<tr>
<th>Year</th>
<th>Gini Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0.97</td>
</tr>
<tr>
<td>2000</td>
<td>0.94</td>
</tr>
<tr>
<td>2014</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Looking at overall trends, as the region has de-industrialized, the number of TRI facilities has declined (from 182 facilities in 1990 to 104 facilities in 2014) (Table 9). Overall, the volume of emissions and toxicity of emissions has also declined from 1990 to 2014. However, when the results from 2014 are compared to 2000, the pollutants being released have higher toxic concentration in 2014. A few key facilities are contributing the most toxic concentration emissions in the region. In all years, over one-third of the region's pollution volume, containing over 85 percent of the region's toxic concentration, has been released by just 10 facilities. The
proportion of toxic concentration from these top emitters was greatest in 2014, with over 97 percent of the toxic concentration emitted by just 10 facilities.
Table 9: Central Puget Sound’s Top 10 TRI Air Pollution Exposure Risk Characterization from 1990 - 2014

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Cluster Type</th>
<th>Pounds</th>
<th>Toxic Concen.(^{13})</th>
<th>Total Toxic Concen. %</th>
<th>Cumulative Toxic Concen., %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSF INDUSTRIES INC.</td>
<td>Transitional</td>
<td>7,955</td>
<td>93,413,596,500</td>
<td>34.05%</td>
<td>34.05%</td>
</tr>
<tr>
<td>WEYERHAEUSER CO., EVERETT PULP MILL</td>
<td>Transitional</td>
<td>786,905</td>
<td>43,262,513,700</td>
<td>15.77%</td>
<td>49.82%</td>
</tr>
<tr>
<td>AMERICAN TAR CO.</td>
<td>Transitional</td>
<td>1,265</td>
<td>42,075,035,000</td>
<td>15.34%</td>
<td>65.15%</td>
</tr>
<tr>
<td>BOEING COMMERCIAL AIRPLANE GROUP</td>
<td>Struggling</td>
<td>1,372,278</td>
<td>15,483,828,100</td>
<td>5.64%</td>
<td>70.80%</td>
</tr>
<tr>
<td>SEATTLE STEEL INC.</td>
<td>Transitional</td>
<td>44,100</td>
<td>12,687,260,000</td>
<td>4.63%</td>
<td>75.42%</td>
</tr>
<tr>
<td>BOEING COMMERCIAL AIRPLANES – EVERETT</td>
<td>Struggling</td>
<td>2,142,097</td>
<td>8,650,145,050</td>
<td>3.15%</td>
<td>78.58%</td>
</tr>
<tr>
<td>PIONEER AMERICAS LLC TACOMA TERMINAL</td>
<td>Prospering</td>
<td>9,161</td>
<td>8,103,271,460</td>
<td>2.95%</td>
<td>81.53%</td>
</tr>
<tr>
<td>KIMBERLY-CLARK WORLDWIDE</td>
<td>Struggling</td>
<td>634,510</td>
<td>7,462,621,970</td>
<td>2.72%</td>
<td>84.25%</td>
</tr>
<tr>
<td>JORGENSEN FORGE CORP</td>
<td>Prospering</td>
<td>795</td>
<td>7,218,074,130</td>
<td>2.63%</td>
<td>86.88%</td>
</tr>
<tr>
<td>SUPERIOR WOOD TREATING</td>
<td>Struggling</td>
<td>765</td>
<td>6,895,582,500</td>
<td>2.51%</td>
<td>89.39%</td>
</tr>
</tbody>
</table>

Top 10 Facility Totals: - 4,999,831 245,251,928,410 89.39% 89.39%
All facility totals (n=182): - 13,547,732 274,312,238,832 100.00% 100.00%

2000

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Cluster Type</th>
<th>Pounds</th>
<th>Toxic Concen.(^{13})</th>
<th>Total Toxic Concen. %</th>
<th>Cumulative Toxic Concen., %</th>
</tr>
</thead>
<tbody>
<tr>
<td>KIMBERLY-CLARK WORLDWIDE</td>
<td>Struggling</td>
<td>1,205,010</td>
<td>7,507,346,030</td>
<td>31.49%</td>
<td>31.49%</td>
</tr>
<tr>
<td>KAISER ALUMINUM TACOMA WORKS</td>
<td>Prospering</td>
<td>114,282</td>
<td>3,820,467,540</td>
<td>16.02%</td>
<td>47.51%</td>
</tr>
<tr>
<td>BOEING COMMERCIAL AIRPLANES – EVERETT</td>
<td>Struggling</td>
<td>504,611</td>
<td>2,097,015,990</td>
<td>8.79%</td>
<td>56.30%</td>
</tr>
</tbody>
</table>

\(^{13}\)The toxic concentration contained in the table is a unitless value that reflects the size of the facilities' releases, the toxicity of the release, and the fate and transport of the chemical through the environment. It is used by the US EPA for screening purposes, and here gives a glimpse into the skewness of pollution sources in the region.
<table>
<thead>
<tr>
<th>Company Name</th>
<th>Status</th>
<th>Employees</th>
<th>Annual Revenues</th>
<th>Revenue %</th>
<th>Profit %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUND PROPELLER SERVICES INC.</td>
<td>Transitional</td>
<td>500</td>
<td>1,791,250,000</td>
<td>7.51%</td>
<td>63.82%</td>
</tr>
<tr>
<td>US NAVY PSNS &amp; IMF - BREMERTON SITE &amp; NAVAL BASE KITSAP</td>
<td>Transitional</td>
<td>118,537</td>
<td>1,651,759,710</td>
<td>6.93%</td>
<td>70.74%</td>
</tr>
<tr>
<td>SIMPSON TACOMA KRAFT CO</td>
<td>Prospering</td>
<td>820,391</td>
<td>1,219,726,000</td>
<td>5.12%</td>
<td>75.86%</td>
</tr>
<tr>
<td>BOEING COMMERCIAL AIRPLANES – AUBURN</td>
<td>Struggling</td>
<td>173,406</td>
<td>704,584,551</td>
<td>2.96%</td>
<td>78.81%</td>
</tr>
<tr>
<td>TTM TECHNOLOGIES INC</td>
<td>Transitional</td>
<td>48,776</td>
<td>655,380,708</td>
<td>2.75%</td>
<td>81.56%</td>
</tr>
<tr>
<td>BRADKEN ENERGY</td>
<td>Struggling</td>
<td>1,075</td>
<td>573,094,781</td>
<td>2.40%</td>
<td>83.97%</td>
</tr>
<tr>
<td>WESTERN PNEUMATIC TUBE CO LLC</td>
<td>Prospering</td>
<td>74,514</td>
<td>491,441,304</td>
<td>2.06%</td>
<td>86.03%</td>
</tr>
<tr>
<td>Top 10 Facility Totals</td>
<td></td>
<td></td>
<td>3,061,102</td>
<td>86.03%</td>
<td>86.03%</td>
</tr>
<tr>
<td>All facility totals (n=117)</td>
<td></td>
<td></td>
<td>5,800,675</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAINT-GOBAIN CONTAINERS INC</td>
<td>Prospering</td>
<td>2,040</td>
<td>13,334,285,900</td>
<td>35.77%</td>
<td>35.77%</td>
</tr>
<tr>
<td>JORGENSEN FORGE CORP</td>
<td>Transitional</td>
<td>1,545</td>
<td>7,463,520,490</td>
<td>20.02%</td>
<td>55.79%</td>
</tr>
<tr>
<td>ALASKAN COPPER WORKS</td>
<td>Transitional</td>
<td>535</td>
<td>7,366,145,490</td>
<td>19.76%</td>
<td>75.54%</td>
</tr>
<tr>
<td>YOUNG CORP MELTEC DIV</td>
<td>Prospering</td>
<td>4,859</td>
<td>3,093,391,200</td>
<td>8.30%</td>
<td>83.84%</td>
</tr>
<tr>
<td>PROTECTIVE COATINGS INC</td>
<td>Struggling</td>
<td>34,721</td>
<td>2,325,805,600</td>
<td>6.24%</td>
<td>90.08%</td>
</tr>
<tr>
<td>SIMPSON TACOMA KRAFT CO</td>
<td>Prospering</td>
<td>933,548</td>
<td>753,213,994</td>
<td>2.02%</td>
<td>92.10%</td>
</tr>
<tr>
<td>US NAVY PSNS &amp; IMF - BREMERTON SITE &amp; NAVAL BASE KITSAP</td>
<td>N/A</td>
<td>55,646</td>
<td>565,437,718</td>
<td>1.52%</td>
<td>93.62%</td>
</tr>
<tr>
<td>GENERAL PLASTICS MANUFACTURING CO</td>
<td>Struggling</td>
<td>11,050</td>
<td>528,143,512</td>
<td>1.42%</td>
<td>95.03%</td>
</tr>
<tr>
<td>BOEING COMMERCIAL AIRPLANES – AUBURN</td>
<td>Struggling</td>
<td>269,084</td>
<td>454,235,186</td>
<td>1.22%</td>
<td>96.25%</td>
</tr>
<tr>
<td>BRADKEN ENERGY</td>
<td>Struggling</td>
<td>1,174</td>
<td>402,886,500</td>
<td>1.08%</td>
<td>97.33%</td>
</tr>
<tr>
<td>Top 10 Facility Totals</td>
<td></td>
<td></td>
<td>1,314,203</td>
<td>97.33%</td>
<td>97.33%</td>
</tr>
<tr>
<td>All facility totals (n=104)</td>
<td></td>
<td></td>
<td>3,928,185</td>
<td>100.00%</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Analysis of the top 10 TRI emitters by neighborhood cluster type reveals variability in the location of the top 10 TRI facility polluters over time (Table 10). In 1990, facility emissions in pounds is heavily concentrated in Struggling cluster types (containing 83 percent of the pounds emitted), but Transitional cluster types, which reported fewer emissions, had higher toxic concentration (containing over 78 percent of the toxic concentration). In 2000, Struggling cluster types lead in the number of facilities (4 facilities), pounds emitted (over 61 percent), and toxic concentration (over 53 percent). But by 2014, Prospering cluster tracts lead in emissions and toxic concentration (71 percent and 47 percent, respectively).

Table 10: Top 10 TRI Facility Statistics, Summarized by Cluster Type and Year, 1990 - 2014

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>Number of Top 10 TRI Facilities</th>
<th>Pounds</th>
<th>Top 10 TRI Pounds %</th>
<th>Toxic Concentration</th>
<th>Top 10 TRI Toxic Concent. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>2</td>
<td>9,956</td>
<td>0.20%</td>
<td>15,321,345,590</td>
<td>6.25%</td>
</tr>
<tr>
<td>Transitional</td>
<td>4</td>
<td>840,225</td>
<td>16.81%</td>
<td>191,438,405,200</td>
<td>78.06%</td>
</tr>
<tr>
<td>Struggling</td>
<td>4</td>
<td>4,149,650</td>
<td>83.00%</td>
<td>38,492,177,620</td>
<td>15.69%</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>3</td>
<td>1,009,187</td>
<td>32.97%</td>
<td>5,531,634,844</td>
<td>26.97%</td>
</tr>
<tr>
<td>Transitional</td>
<td>3</td>
<td>167,813</td>
<td>5.48%</td>
<td>4,098,390,418</td>
<td>19.98%</td>
</tr>
<tr>
<td>Struggling</td>
<td>4</td>
<td>1,884,102</td>
<td>61.55%</td>
<td>10,882,041,352</td>
<td>53.05%</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>3</td>
<td>940,447</td>
<td>71.56%</td>
<td>17,180,891,094</td>
<td>47.35%</td>
</tr>
<tr>
<td>Transitional</td>
<td>2</td>
<td>2,080</td>
<td>0.16%</td>
<td>14,829,665,980</td>
<td>40.87%</td>
</tr>
<tr>
<td>Struggling</td>
<td>4</td>
<td>316,029</td>
<td>24.05%</td>
<td>3,711,070,798</td>
<td>10.23%</td>
</tr>
</tbody>
</table>
When analyzing total TRI facilities, a similar variability exists (Table 11). In 1990, facility emissions in pounds is highest in Prospering clusters (47 percent), but Transitional cluster types, which reported fewer emissions, had higher toxic concentration (70 percent). In 2000, Struggling cluster types lead in the number of facilities (43 facilities), pounds emitted (44 percent), and toxic concentration (50 percent). But again by 2014, Prospering cluster tracts lead in emissions and toxic concentration (69 percent and 48 percent, respectively). While this may appear, at first glance, to suggest that environmental inequality within the region is reducing over time, this finding is not supported when exposure impacts of multiple facilities on neighboring residents are examined, as analyzed in the Pollution Exposure Risk section below.

Table 11: All TRI Facility Statistics, Summarized by Cluster Type and Year, 1990 - 2014

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>Number of TRI Facilities</th>
<th>Pounds</th>
<th>Total TRI Pounds %</th>
<th>Toxic Concentration</th>
<th>Total TRI Toxic Concen. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>110</td>
<td>6,425,898</td>
<td>47.4%</td>
<td>34,941,575,138</td>
<td>12.7%</td>
</tr>
<tr>
<td>Transitional</td>
<td>40</td>
<td>1,720,427</td>
<td>12.7%</td>
<td>193,995,199,731</td>
<td>70.7%</td>
</tr>
<tr>
<td>Struggling</td>
<td>32</td>
<td>5,401,406</td>
<td>39.6%</td>
<td>45,375,463,962</td>
<td>16.5%</td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>38</td>
<td>1,969,465</td>
<td>34.0%</td>
<td>6,977,849,041</td>
<td>29.3%</td>
</tr>
<tr>
<td>Transitional</td>
<td>36</td>
<td>1,244,800</td>
<td>21.5%</td>
<td>4,877,367,406</td>
<td>20.5%</td>
</tr>
<tr>
<td>Struggling</td>
<td>43</td>
<td>2,586,410</td>
<td>44.6%</td>
<td>11,988,411,158</td>
<td>50.3%</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>43</td>
<td>2,732,430</td>
<td>69.6%</td>
<td>17,943,682,187</td>
<td>48.1%</td>
</tr>
<tr>
<td>Transitional</td>
<td>30</td>
<td>276,979</td>
<td>7.1%</td>
<td>14,926,213,666</td>
<td>40.0%</td>
</tr>
<tr>
<td>Struggling</td>
<td>29</td>
<td>862,569</td>
<td>22.0%</td>
<td>3,832,903,981</td>
<td>10.3%</td>
</tr>
</tbody>
</table>

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This fluctuating pattern is influenced by two simultaneous processes: spatial redistribution of top TRI polluting facilities and neighborhood changes (Figure 18 through Figure 20). In 1990, the pollution sources are distributed throughout the region, occurring in 71 census tracts (Figure 18). The top 10 emitters are similarly distributed throughout the region. By 2014, the TRI landscape has changed dramatically (Figure 20). There is a substantial reduction in the number of facilities, but the reduction in facilities has not been evenly distributed. By 2014, only 51 census tracts host TRI facilities; the most substantial reduction in host census tracts occurs in the north and east areas of the region. In many cases, TRI facilities are eliminated within areas experiencing infill and redevelopment; as an example, 21 of 24 facilities in areas that are now designated as Urban Growth Centers under Vision 2040 have relocated or ceased operation. At the same time, the region's top 10 emitters have concentrated in the southern portion of the region. In particular, a large concentration of high toxic concentration emitters have consolidated in the South Seattle area, which by 2014 contains the top four facilities releasing the highest toxic concentration, accounting for over 83% of the region's toxic concentration.

These changes are associated with increasing concentration of major industrial facilities within regionally designated Manufacturing Industrial Centers (MICs). This pattern is consistent with industrial gentrification observed by Abel et al (2015), in which redevelopment and gentrification occurring throughout the region are displacing industrial activities, resulting in concentration of remaining industrial activities. Comparing the industrial landscape in 1990 to 2014, an increasing number of facilities and the largest emitters are located within MICs (Table 12). By 2014 over 94 percent of the facilities contributing to toxic concentration levels in the region are located within MICs, an increase of almost 40 percent from 1990. Duwamish and
North Tukwila MICs have the greatest burden, disproportionately hosting emitters with the highest toxic concentration throughout the region.

**Table 12: TRI Facility Statistics, Summarized by Manufacturing Industrial Centers (MICs) and other Industrial Zoning, 1990 - 2014**

<table>
<thead>
<tr>
<th></th>
<th>% TRI Facilities in MICs</th>
<th>Top 10 Facilities in MICs</th>
<th>% Toxic Concentration from Facilities in MICs</th>
<th>% TRI Facilities in other Industrial Zones</th>
<th>Top 10 Facilities in Other Industrial Zones</th>
<th>% Toxic Concentration from Facilities in Other Industrial Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>41.8%</td>
<td>50%</td>
<td>54.8%</td>
<td>38.0%</td>
<td>40%</td>
<td>5.7%</td>
</tr>
<tr>
<td>2000</td>
<td>46.3%</td>
<td>30%</td>
<td>39.0%</td>
<td>34.7%</td>
<td>70%</td>
<td>52.4%</td>
</tr>
<tr>
<td>2014</td>
<td>54.7%</td>
<td>60%</td>
<td>94.3%</td>
<td>30.6%</td>
<td>40%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

Analysis of the location of pollution sources has identified skewness in the distribution of pollution sources, with pollution sources spatially concentrating over time, but the information is not sufficient to conclude whether or not this distribution has resulted in unequal risk to neighboring communities. To examine this issue, I next turn to analyze risk exposure across the region.
Figure 18: TRI Facilities in the Central Puget Sound region, 1990
Figure 20: TRI Facilities in the Central Puget Sound region, 2014
Pollution Exposure Risk

Whereas the previous section focuses on the location and emissions of pollution sources, this section analyzes the resulting risk exposure impacts to neighboring communities from these facilities. First, the analysis reveals that the unevenness observed in the distribution of pollution sources is reflected in the distribution of exposure risk. In all years, a Gini coefficient evaluating each census tract's proportion of toxic concentration to the cumulative regional toxic concentration returned results greater than 0.60 (Table 13), revealing a relatively high degree of inequality in the distribution of exposure across census tracts. These values are also similar to the national level between-tract Gini Coefficient of 0.76 calculated by Boyce et al. (2016), based on 2010 RSEI information.

Table 13: Gini Coefficient for RSEI-GM in each census tract as proportion of cumulative estimated regional exposure

<table>
<thead>
<tr>
<th>Year</th>
<th>Gini Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-1994</td>
<td>0.70</td>
</tr>
<tr>
<td>2000-2004</td>
<td>0.67</td>
</tr>
<tr>
<td>2010-2014</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Unevenness in the regional riskscape is reflected in the spatial distribution of toxic concentration (Figure 21 through Figure 23). In each year, results of a spatial cluster analysis (Anselin's Moran's I) reveals regions where the toxic concentration values are statistically significantly higher than surrounding census tracts (denoted as 'High-High' cluster tracts).

---

14 The Gini Coefficient values declined from 0.70 to 0.65 between 1990 and 2010. While this could be interpreted as evidence of a decrease in the riskscape skewness, it is important to note that this measure only examines spatial inequality in exposure levels, and does not evaluate how that inequality is associated with the characteristics of communities impacted by the pollution, defined as patterned inequality by Walker (2012). Therefore, this measure alone is insufficient on its own to determine how different neighborhood types are disproportionately impacted by exposure risk.
Exposure risk is concentrated in a small number of census tracts and has become increasingly more spatially consolidated in the South Seattle area over time. In 1990, toxic concentration was highest in two distinct regions, one located near Everett and the other located in Seattle. The predominant neighborhood type within the area of high toxic concentration is Struggling (28 census tracts, or 48 percent of the census tracts in the cluster) (Figure 21). In 2000, the Everett cluster diminishes in size, and a new cluster emerges in Bremerton. The predominant neighborhood type within the area of high toxic concentration shifts to Transitional (30 census tracts, or over 51 percent) (Figure 22). By 2014, Everett no longer contains an area of high toxic concentration. Instead, the cluster has consolidated in the South Seattle area. Struggling neighborhoods are the most predominant neighborhood type within the toxic concentration hotspot (28 census tracts, or over 48 percent) (Figure 23).

This result differs from the results contained in the Pollution Sources section above that focused on the neighborhood composition of census tracts hosting pollution facilities, which found that in 2014, Prospering neighborhoods hosted the TRI facilities with the greatest emissions and toxic concentration. These contradictory findings highlight the limitations of unit-hazard coincidence methods. Unit-hazard coincidence methods only look at the neighborhood characteristics of the census tracts hosting a facility, no matter where the facility may be located within the host census tract, and further do not account for other variables, such as prevailing winds. The limitations of this methodological approach have been critiqued by many researchers, as detailed most recently by Mohai and Saha (2015) in their longitudinal analysis of environmental justice studies. Instead, when pollution exposure risk from multiple facilities is modeled as part of the RSEI geographic microdata, a more granular pattern of exposure risk is revealed. In this case, the more granular level data reveal that exposure risks are
highest for Struggling communities, which are located in the pollution plume pathways of multiple facilities.
Figure 21: High Toxic Concentration Clusters, 1990-1994
Figure 22: High Toxic Concentration Clusters, 2000-2004
Figure 23: High Toxic Concentration Clusters, 2010-2014
Table 14 highlights the amount of toxic concentration that is impacting census tracts within these regional clusters. In 1990, 58 census tracts comprised the region's hotspots of high toxic concentration, accounting for 55 percent of the region's toxic concentration. By 2014, over 56 percent of the regional toxic concentration is contained in the hotspot in South Seattle. Therefore, like pollution sources, there is unevenness in risk exposure across the region, with spatial concentration occurring in South Seattle by 2014. Next, I turn to analyze whether this unevenness has resulted in risk burdens that are not shared equally by different subgroups of the overall population.

Table 14: Proportion of Toxic Concentration contained in High-High Clusters, 1990 - 2014

<table>
<thead>
<tr>
<th>Cluster of High Toxic Concentration</th>
<th>% of Total census tracts in Region (n=739)</th>
<th>% of Total Regional Toxic Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-1994</td>
<td>7.8%</td>
<td>55.1%</td>
</tr>
<tr>
<td>2000-2004</td>
<td>7.8%</td>
<td>49.1%</td>
</tr>
<tr>
<td>2010-2014</td>
<td>11.8%</td>
<td>56.9%</td>
</tr>
</tbody>
</table>

Impacted Communities

Analysis of the socioeconomics and demographics of the communities impacted by high toxic concentration reveals a pattern of environmental inequality. On a region-wide scale, one-way ANOVA was used to assess whether the type of neighborhood (Prospering, Transitional and Struggling) had an effect on exposure risk. The results revealed that in all years, there are statistically significant differences in the RSEI Toxic Concentration values across the three neighborhood clusters (Table 15). Further, post hoc comparisons using the Tukey test indicate that exposure risks for Struggling neighborhoods were significantly higher than for Prospering
and Transitional clusters. There was no statistically significant difference in exposure risk between the Prospering and Transitional clusters.

*Table 15: One-way ANOVA: Neighborhood cluster type with RSEI Toxic Concentration, 1990 - 2010*

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>187.7</td>
<td>26.2</td>
<td>66.5</td>
</tr>
<tr>
<td>Transitional</td>
<td>264.0</td>
<td>47.7</td>
<td>69.9</td>
</tr>
<tr>
<td>Struggling</td>
<td>829.1***/***(^{15})</td>
<td>100.8***/***(^{15})</td>
<td>125***/*(^{15})</td>
</tr>
<tr>
<td>F-value(^{16})</td>
<td>F(2,736)=18.673***</td>
<td>F(2,736)=17.041***</td>
<td>F(3,735)=4.659***</td>
</tr>
</tbody>
</table>

\(^{15}\) Association with Prospering/Association with Transitional

\(^{16}\) A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric results were completed, and the results compared with each other. Since the results were consistent with each other, only the results from the parametric tests are reported. Levene's test confirmed that there was homogeneity in the variances.

In addition, comparing differences in exposure risks by neighborhood types within hotspots and areas outside of these hotspots also revealed that where exposure risk is highest; Struggling clusters continue to be the most disproportionately impacted (Table 16). Census tracts within the cluster of high toxic concentration have significantly higher toxic concentration than other census tracts outside of this hotspot for all years. Further, Struggling cluster types within the hotspot have a higher exposure value than other neighborhood types. Post hoc comparisons using the Tukey test indicated that exposure risks for Struggling neighborhoods was significantly higher, as compared to Prospering clusters, for 1990 and 2000. There was no
statistically significant difference in exposure risk between other neighborhood types. Further, there was no statistically significant difference in exposure risk between neighborhood types located within exposure hotspots in 2010.

Table 16: One-way ANOVA: Comparison between Cluster of High Toxic Concentration and All Other census tracts, by Neighborhood Types, 1990 - 2010

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cluster of High Toxic Concentration - Exposure Risk Values</strong>*17**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>1,200.7</td>
<td>179.4</td>
<td>381.7</td>
</tr>
<tr>
<td>Transitional</td>
<td>2,004.8</td>
<td>288.8</td>
<td>372.1</td>
</tr>
<tr>
<td>Struggling</td>
<td>2,544.3***/ Not sig.18</td>
<td>347.4*/ Not sig.18</td>
<td>397.0</td>
</tr>
<tr>
<td><strong>All Other census tracts - Exposure Risk Values</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospering</td>
<td>165.0</td>
<td>24.2</td>
<td>42.9</td>
</tr>
<tr>
<td>Transitional</td>
<td>109.0</td>
<td>20.4</td>
<td>31.2</td>
</tr>
<tr>
<td>Struggling</td>
<td>205.4</td>
<td>49.3</td>
<td>49.0</td>
</tr>
<tr>
<td><strong>F-value</strong>19**</td>
<td>F(5,733)=69.106***</td>
<td>F(5,733)=82.738***</td>
<td>F(7,731)=75.162***</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001

In addition, Struggling clusters have a higher percentage of census tracts within the hotspots of high toxic concentration, as compared to both Prospering and Transitional cluster

---

17 Association between Cluster of High Toxic Concentration and All Other census tracts – Census tracts in hotpot have statistically higher exposure risk values than all other Census tracts

18 Association with Prospering/Association with Transitional

19 A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric results were conducted, and the results compared with each other. Since the results were consistent with each other, only the results from the parametric tests are reported. Levene's test confirmed that there was homogeneity of the variances.
types (Figure 24). A higher proportion of census tracts classified as Struggling are impacted by high toxic concentration than either Prospering or Transitional cluster types. This inequality persists in all years of the study period.

![Figure 24: Percentage of Neighborhood cluster within area of High Toxic Concentration, 1990-2014](image)

Taken together, these results suggest that Struggling communities face a disproportionate risk burden, both region-wide and within hotspots of toxic concentration. This disproportionate burden has persisted in all years, despite an overall trend of deindustrialization and spatial
changes in industrial patterns. As noted in Section 4.1.1, Struggling clusters comprise census tracts containing a higher proportion of minorities, low-income, and non-traditional families, suggesting that socioeconomics and demographics do have a substantial effect on exposure risk in the region.

4.2.2. Cumulative Assessment of Air-Quality Hazards

In this section, I analyze the cumulative air quality environmental hazards from three different sources: large-scale point-source facilities, ambient air toxics, and small-scale point source facilities. Areas of high concentration of each of these hazards are aggregated to depict a composite identifying the area most impacted by multiple hazard types. This section concludes with analysis of the communities most impacted by the cumulative hazards. Additional details on these three sources of air pollution risk are located in Appendix D.

Cumulative Pollution Exposure Risk

Analysis of the multiple, overlapping sources of pollution reveals that cumulative pollution exposure is extremely skewed, with only 19 census tracts in the region having the greatest exposure to various point and ambient pollution sources (Figure 25). Exposure risk is concentrated in Central and South Seattle, where centers of employment, heavy industry and goods-transportation, and traffic congestion all converge.
Figure 25: Composite of Cumulative Riskscape, 2010
Impacted Communities

Analysis of the cumulative hazards reveals that this socio-spatial inequality is associated with demographic and socioeconomic patterns. On a region-wide scale, results from one-way ANOVA revealed statistically significant differences in the mean risk values between the three neighborhood clusters for all environmental hazards evaluated (RSEI Toxic Concentration, NATA cancer and non-cancer scores, and Small Source Facility concentration) (Table 17). For all variables, mean values were highest in Struggling communities, with varying levels of statistical significance.

For RSEI Toxic Concentration, post hoc comparisons using the Tukey test indicated that exposure risk was statistically higher for Struggling clusters, as compared to Prospering (+58.6, p=0.0004) and Transitional (+55.2, p=0.011) clusters. There was no statistically significant difference between the Prospering and Transitional clusters (p=0.996). For NATA Cancer, post hoc comparisons indicated that risk scores were significantly higher for Struggling clusters (+4.9, p=0.045), as compared to Prospering clusters. There was no statistically significant difference between the Prospering and Transitional clusters or Transitional and Struggling clusters. For NATA Non-Cancer, risk was significantly higher for Struggling clusters, as compared to Prospering (+0.8, p<0.001) and Transitional (+1.0, p<0.001) clusters. There was no statistically significant difference between the Prospering and Transitional clusters (p=0.399). Finally, for Small Facilities, concentration was significantly higher for Struggling clusters, as compared to Prospering clusters (+0.001, p<0.001). There was no statistically significant difference between the Struggling and Transitional clusters (p=0.067) or Prospering and Transitional clusters (p=0.100).
Table 17: One-way ANOVA: Neighborhood cluster type with Environmental Factors, 2010

<table>
<thead>
<tr>
<th></th>
<th>RSEI</th>
<th>NATA Cancer</th>
<th>NATA Non-Cancer</th>
<th>Small Source Facility Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prospering</strong></td>
<td>66.5</td>
<td>48.9</td>
<td>3.7</td>
<td>.001</td>
</tr>
<tr>
<td><strong>Transitional</strong></td>
<td>69.9</td>
<td>47.0</td>
<td>3.5</td>
<td>.002</td>
</tr>
<tr>
<td><strong>Struggling</strong></td>
<td>125***/*20</td>
<td>52.0*/Not. Sig.20</td>
<td>4.8***/*30</td>
<td>.003***/Not. Sig.20</td>
</tr>
<tr>
<td><strong>F-value</strong></td>
<td>F(3,735)=</td>
<td>F(3,735)=</td>
<td>F(3,735)=</td>
<td>F(3,735)=</td>
</tr>
<tr>
<td></td>
<td>4.659 **</td>
<td>4.156**</td>
<td>14.835***</td>
<td>7.350***</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, ***p<0.001

Comparing differences in cumulative risks by neighborhood types within hotspots and areas outside of these hotspots also revealed spatial differences in exposure.

Table 18 presents the results of one-way ANOVA tests completed that compared risk values for all environmental variables in the clusters of high cumulative risk with areas outside the cluster, by neighborhood type. First, mean values for all variables are higher within the cumulative risk hotspot, and the differences in values are statistically significant for all variables and all neighborhood types. However, as opposed to the region-wide mean values, the mean

---

20 Association with Prospering/Association with Transitional

21 A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric results were conducted, and the results compared with each other. Since the results were consistent with each other, only the results from the parametric tests are reported. Levene’s test confirmed that there was homogeneity of the variances.
values within the hotspot show variability by neighborhood type. Prospering cluster types have higher mean Toxic Concentration values, while Transitional clusters have higher NATA (cancer and non-cancer) values (Table 18). The finding concerning RSEI Toxic Concentration values is not surprising, as the Georgetown neighborhood (located within a Prospering cluster) is located downwind from the facility with the highest regional toxic concentration value in 2014 (Saint-Gobain). Likewise, the Transitional areas like the Industrial District are significantly impacted by mobile emissions from a variety of sources, including freight, rail, port, and congested highways. The differences in mean values within the hotspot are statistically significant for NATA Cancer and Small Scale facilities only.
### Table 18: One-way ANOVA: Comparison between Cluster of Cumulative Risk and All Other census tracts, by Neighborhood Types, 2010

<table>
<thead>
<tr>
<th></th>
<th>RSEI</th>
<th>NATA Toxic Con.</th>
<th>NATA Cancer</th>
<th>NATA Non-Cancer</th>
<th>Small Source Facility Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hotspot of Cumulative Risk - Mean Values</strong>*22**</td>
<td><strong>Prospering</strong></td>
<td>562.4</td>
<td>108.7</td>
<td>8.0</td>
<td>0.02*/Not Sig.24</td>
</tr>
<tr>
<td></td>
<td><strong>Transitional</strong></td>
<td>449.4</td>
<td>115.3 Not Sig./***23</td>
<td>8.3</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td><strong>Struggling</strong></td>
<td>429.2</td>
<td>79.0</td>
<td>6.4</td>
<td>0.02</td>
</tr>
</tbody>
</table>

|                          | **All Other census tracts - Mean Values** | **Prospering** | 61.8 | 48.3*/Not Sig.24 | 3.6 | 0.001 |
|                          | **Transitional** | 53.4 | 44.1*/***23 | 3.2 | 0.002 |
|                          | **Struggling** | 114.7 | 51.1 Not Sig./*25 | 4.4 | 0.003 ***/Not Sig.25 |

| F-value26               | F(6,732)=20.620 *** | F(6,732)=47.844*** | F(6,732)=33.914*** | F(6,732)=33.692*** |

*p<0.05, **p<0.01, ***p<0.001

---

22 Association between Hotspot and All Other census tracts – Census tracts in hotspot have statistically higher values than all other Census tracts
23 Association with Prospering/Association with Struggling
24 Association with Transitional/Association with Struggling
25 Association with Prospering/Association with Transitional
26 A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric results were conducted, and the results compared with each other. Since the results were consistent with each other, only the results from the parametric tests are reported. Levene's test confirmed that there was homogeneity of the variances.
For RSEI Toxic Concentration and NATA Non-Cancer, post hoc comparisons using the Tukey test indicated did not reveal a statically significant difference in the mean RSEI values between neighborhood types within the hotspot of cumulative risk. For NATA Cancer, post hoc comparisons using the Tukey test indicated that risk scores were statistically higher for Transitional clusters (+36.3, p<0.001), as compared to Struggling clusters. There was no statistically significant difference between the Prospering and Transitional clusters or Prospering and Struggling clusters. For Small Scale facilities, post hoc comparisons using the Tukey test indicated that concentration was statistically higher for Prospering clusters (+0.008, p=0.023), as compared to Transitional clusters. There was no statistically significant difference between the Prospering and Struggling clusters or Transitional and Struggling clusters.

Taken together, these results suggests two separate findings: first, throughout the region, Struggling communities face a disproportionate cumulative risk burden, with significantly higher average values in the four environmental factors examined; and second, when only examining the region's cumulative hotspot (located in Downtown Seattle and southward in the Duwamish Valley as depicted in Figure 25), the differences between neighborhood types does not exhibit the same degree of variability. Instead, for the majority of environmental factors, there is no statistically significant difference in exposure values among the neighborhood types. This first finding is consistent with a regional pattern of inequality, while the second highlights the potential for this pattern to be upended by a number of different simultaneous processes. These processes include concentration of pollution, particularly ambient sources, in congested areas, together with 'Back to the City' gentrification, which is placing a greater exposure risk burden on wealthier residents who are choosing to move into areas with good access (to jobs, entertainment, and other amenities) and potentially higher exposure.
4.3. Healthscape

Health is affected by neighborhood conditions, including social factors like poverty, unemployment, housing and education, as well as environmental factors, like exposure to pollution. Planning has an important role in shaping various neighborhood conditions that contribute to health outcomes. The healthscape section of this study examines trends in health outcomes as well as explores the relationship between social and environmental factors, with the objective of understanding whether regional planning is leading to equitable health outcomes. The approach is twofold. First, I analyze trends in asthma hospitalization rates to determine the trajectory of one particular type of health outcome (asthma) associated with air pollution over time. I also examine the spatial patterns of asthma hospitalization rate changes over time, coupled with the neighborhood changes discussed in Section 3.1, to determine if there is inequality in the distribution of these changes. Second, I present correlation results assessing the relationship of asthma hospitalization rates with socioeconomic and environmental exposure factors previously addressed in Section 4.1 and 4.2, respectively.

4.3.1. Longitudinal Analysis of Asthma Hospitalization Rates

Analysis of the region's asthma hospitalization rates reveals that the average rate of hospitalization has been increasing over time (Table 19). In all years, Struggling cluster types have a higher hospitalization rate than either Prospering or Transitional cluster types. The Gini Coefficient, which is a measure of mean difference that has been used in studies of health inequality (Brendt et al. 2003; Levy et. al 2007; Levy et al. 2009), is near 0.50 for all years, indicating a moderate level of unevenness in asthma-related hospitalization.
Table 19: Descriptive Statistics and Gini Coefficient for Asthma Hospitalization Rates, Central Puget Sound, 1990-2014

<table>
<thead>
<tr>
<th>Year</th>
<th>Region-Wide Hospitalization Rate (per 100,000)</th>
<th>Prospering Cluster Type Hospitalization Rate (per 100,000)</th>
<th>Transitional Cluster Type Hospitalization Rate (per 100,000)</th>
<th>Struggling Cluster Type Hospitalization Rate (per 100,000)</th>
<th>Gini Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>29.7</td>
<td>26.7</td>
<td>26.2</td>
<td>49.2</td>
<td>0.54</td>
</tr>
<tr>
<td>2000</td>
<td>55.5</td>
<td>46.0</td>
<td>54.9</td>
<td>77.6</td>
<td>0.51</td>
</tr>
<tr>
<td>2014</td>
<td>68.5</td>
<td>55.3</td>
<td>66.6</td>
<td>97.2</td>
<td>0.49</td>
</tr>
</tbody>
</table>

The spatial pattern of the unevenness is depicted in Figure 26 through Figure 28. In all years, hotspots emerge near downtown Seattle, south of Tacoma near McChord Air force Base, Puyallup, Kent, and Auburn. The next section turns to examine the relationship between these spatial patterns and social and environmental variables.
Figure 26: Asthma Hospitalization Rates, Central Puget Sound region, 1990
Figure 27: Asthma Hospitalization Rates, Central Puget Sound region, 2000
Figure 28: Asthma Hospitalization Rates, Central Puget Sound region, 2014
4.3.2. Relationship between Socioeconomic and Environmental Exposure Factors and Asthma Hospitalization Rates

Health is a complex condition to analyze, given the broad number of factors that can work independently and together to impact health outcomes (Braverman et al. 2011). Despite this complexity, the bivariate analysis identified a weak, but statistically relationship between social and environmental factors and asthma hospitalization rates in the Central Puget Sound region.

A variety of parametric correlation tests were conducted to examine the relationship between asthma hospitalization rates and socioeconomic (neighborhood Cluster type) and environmental exposure (RSEI Toxic Concentration, NATA Non-Cancer Scores, Small Source Air Pollution Source Density) variables. The results in Table 20 indicate that the RSEI Toxic Concentration, NATA Non-Cancer scores, and Small Source Facility Concentration are positively and significantly correlated with asthma hospitalization rates, indicating that census tracts with higher toxic concentration, non-cancer risk, and small-source facility concentration have higher hospitalization rates for asthma. The correlation coefficient values for these variables, which are all below 0.3, are fairly low, reflective of the complexity of issues that contribute to health outcomes.
The results in Table 20 also indicated that neighborhood Cluster type (Prospering, Transitional and Struggling) is positively and significantly associated with asthma hospitalization rates. A one-way ANOVA was then performed to evaluate the difference in asthma hospitalization rates among neighborhood Cluster types.

Table 21: One-way ANOVA: Neighborhood cluster type association with asthma hospitalization rate

<table>
<thead>
<tr>
<th>Neighborhood predictors</th>
<th>Asthma Hospitalization Rate (per 100,000) in 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospering</td>
<td>55.3</td>
</tr>
<tr>
<td>Transitional</td>
<td>66.6</td>
</tr>
<tr>
<td>Struggling</td>
<td>97.2***/***</td>
</tr>
<tr>
<td>F-value(^{27})</td>
<td>F(3,735) = 11.549***</td>
</tr>
</tbody>
</table>

\(^{27}\) A test for normality of the variables revealed that the data were not normally distributed. Both non-parametric and parametric results were completed, and the results compared with each other. Since the results were consistent with each other, only the results from the parametric tests are reported. Levene's test confirmed that there was homogeneity in the variances.
There are statistically significant differences in the asthma hospitalization rate between the three neighborhood clusters (Table 21). A Tukey post hoc rest revealed that the asthma hospitalization rate was statistically higher for Struggling clusters, as compared to Prospering (+41.9, \( p<0.001 \)) and Transitional (+30.6, \( p<0.001 \)) clusters. There was no statistically significant difference between the Prospering and Transitional clusters (\( p=0.267 \)). As noted in Section 4.1.1, Struggling clusters comprise census tracts containing a higher proportion of minorities, low-income, and non-traditional families, suggesting that socioeconomics and demographics do have a significant effect on health outcomes in the region.

**Chapter 5. Discussion**

The Puget Sound Region has undergone a substantial transformation since the adoption of the first regional planning growth strategy, *Vision 2020*, in 1990. This document, the predecessor to *Vision 2040*, contained many of the same strategies to limit sprawl, focus growth into designated centers, and improve connectivity to and within urban centers. This framework provides the backbone for the region's approach to protecting the region's people, prosperity and planet. In this chapter, I review three key claims made in the *Vision 2040* approval process and by Smart Growth proponents to evaluate whether these claims are supported by the evidence analyzed in this study: 1) an urban centers-based development strategy is more socially equitable than dispersed development; 2) an urban centers-based development strategy will reduce air quality pollution; and 3) an urban centers-based development strategy ensures that "all residents of the region, regardless of social or economic status, live in a healthy environment, with minimal exposure to pollution" (PSRC 2009, p. 30).
5.1. **Social Equity**

One of the key claims that PSRC made in adopting *Vision 2040* was that the regional approach towards development, which was based on an urban centers focused growth strategy, was more socially equitable than dispersed growth. This claim is based, in part, on beliefs that Smart Growth addresses economic disparities by increasing housing choice and reducing the exclusionary impacts of single-family residences (Arigoni 2001; Pollard 2000; Powell 2007; US EPA n.d.).

Viewed at the regional level, there would appear to be many positive indicators that the region is making steps toward greater inclusion. The region has added 625,900 jobs in the 25-year time frame between 1990 and 2015 (Simonson 2016) and ranked 11th of 100 largest metropolitan areas in terms of regional economic growth between 2004 and 2014 (Brookings 2016), with increases in jobs (+14.1%), gross metropolitan product (GMP) or the value of goods and serviced produced (+33.2%), and aggregate wages (+31.8%). Further, in *Brookings Metro Monitor* (2016), the region ranked 3rd out of the 100 largest metropolitan areas in terms of prosperity, which refers to the wealth and income produced by an economy on a per-capita or per-worker basis. Measures to gauge prosperity included average wage (+15.5%), GMP per job (+16.8%), GMP per capita (+14.6%). Finally, as part of its monitoring of the implementation of *Vision 2040*, PSRC’s has analyzed housing affordability in the region, measured through an Affordability Index that compares income to monthly owner payments. This analysis indicates that more of the homes on the market are affordable at the median family income level (Hubner 2015a).

Yet, questions have been raised about whether the region-wide gains in economic prosperity have been distributed equally across the region. Dierwechter (2014) was first to
evaluate the empirical results of Smart Growth planning in the Central Puget Sound region. Using a combination of construction permit data and case studies of select fast changing neighborhoods, Dierwechter analyzed the regional growth strategy's impact on racial and economic desegregation. Dierwechter's review of permit data for the region between 1990 and 2010 reveals that housing development in fast-changing census tracts remains at least partially segregated, with many tracts being dominated by development of a single type of housing (e.g., single family or multi-family) rather than including a range of different kinds of housing to accommodate a range of incomes. Dierwechter's case studies also reveals varying levels of success and failure of Smart Growth policy implementation in reducing income and racial segregation in the region. Northwest Landing, a development located in Dupont, south of Tacoma, was racially inclusive but remained economically segregated, as compared to surrounding cities. Redmond, to the east of Seattle and Bellevue and home to tech companies such as Microsoft, offered a wide range of housing, but remained economically segregated. The core of Seattle, which has seen substantial infill and redevelopment as part of the 'Back to the City' movement, experienced increased segregation, with "(mostly) White populations of (increasingly wealthy) 'urban villagers' collapsing inward (and away) from Blacks and Hispanics/Latinos and the poor in particular" (Dierwechter 2014, p. 709). At the same time, other places, like Fife, showed signs of relative economic and racial inclusion. In conclusion, Dierwechter remarks "Smart growth across Greater Seattle…struggles to reverse very strong, long-subsidized forces that produce regionally scattered, haphazard development" (p. 709). The region has a continuum of successes and failures, in part because Smart Growth is being implemented onto a varied landscape that has been shaped by historically embedded socioeconomic patterns.
I similarly assess the socioeconomic equality outcomes of this strategy over a 20-year time frame, complementing Dierwecther’s analysis of construction permitting with a longitudinal analysis of neighborhood change, both at the regional scale and within designated regional growth centers. When viewed at a granular scale, as done in this study, it appears that the region-wide benefits are concentrated in certain Prospering areas in the region. In 1990, the difference between median household income between Prospering and Struggling clusters was $27,461. By 2010, this gap had reached $38,868, an increase of $11,407 or over 41 percent. Incomes rose faster in Prospering (27 percent) versus Struggling (13 percent) clusters between 1990 and 2010. Similarly, in terms of housing value, in 1990 the difference between median household value between Prospering and Struggling clusters was $103,626, but by 2010 the gap had increased by $62,249 to $165,875, more than the average value of homes in Struggling clusters. These results are supported by analysis in PolicyLink’s National Equity Atlas, which shows regional income inequality increasing between 1990 and 2012, measured by both the 95/20 ratio (derived from dividing the 95th percentile income by the 20th percentile income) and the Gini Index (PolicyLink 2016).

Housing values and incomes have a direct bearing on housing affordability, the most important concern voiced by minority and low-income residents during the recent Vision 2040 adoption process. Table 22 contains a breakdown of a Housing Affordability Index (HAI) adapted from methods devised by University of Washington's Runstad Center for Real Estate Studies. The index measures the ability of a middle-income family to carry the mortgage payments on a median price home, and has been adapted to also evaluate the ability to pay rent. When the index is 100 there is a balance between the family’s ability to pay and the cost. Higher indexes indicate housing is more affordable. In general, the index for owners has been rising,
the result of historic low interest rates that have reduced monthly payments. The index for renters has been declining, indicating that rental units are becoming less affordable. However, the index reveals sharp divides between housing affordability for Prospering and Transitional versus Struggling clusters. The indexes for Struggling clusters is below 100 for both owner and renter status for all years, indicating that regionally priced homes are not affordable to communities in this cluster type. Moreover, affordability for rental units in the region has been declining over time. This is of particular concern, since Struggling clusters have a lower percentage of home ownership (38.7 percent, compared with over 60 percent at the regional average). The key takeaway is that households at the lower end of the economic spectrum are finding it increasingly difficult to obtain affordable housing in the region. Incomes for communities in Struggling clusters have increased slowly, and have not been able to keep up with substantial increases in regional housing values.

Table 22: Housing Affordability Index, 1990 - 2014, adapted from University of Washington's Runstad Center for Real Estate Studies (Note: If index = 100, there is a balance between the household's ability to pay and the cost. Higher indexes indicate housing is more affordable, and lower indexes are less affordable).

<table>
<thead>
<tr>
<th>Year</th>
<th>Prospering</th>
<th>Transitional</th>
<th>Struggling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Owner)</td>
<td>(Owner)</td>
<td>(Owner)</td>
</tr>
<tr>
<td>1990</td>
<td>101.95</td>
<td>78.17</td>
<td>53.01</td>
</tr>
<tr>
<td></td>
<td>(Renter)</td>
<td>125.70</td>
<td>85.24</td>
</tr>
<tr>
<td>2000</td>
<td>111.78</td>
<td>82.60</td>
<td>55.85</td>
</tr>
<tr>
<td></td>
<td>(Renter)</td>
<td>128.08</td>
<td>86.61</td>
</tr>
<tr>
<td>2010</td>
<td>138.72</td>
<td>101.26</td>
<td>64.29</td>
</tr>
<tr>
<td></td>
<td>(Renter)</td>
<td>112.88</td>
<td>71.67</td>
</tr>
</tbody>
</table>

28 Based on derived mortgage payments of the regional housing value. Mortgage rate values from http://www.freddiemac.com/pmms/pmms30.htm. Assumes 20 percent down payment and no more than 25 percent of monthly income.

29 Based on regional average gross rent payments. Assumes no more than 25 percent of monthly income.
In addition, the number of clusters classified as Struggling has increased over this time period, indicating that more communities are not participating in the economic growth of the region, but instead are declining in relative socioeconomic status. Further, success has not been spread evenly across the region. Instead, spatial analysis shows that the region is spatially divided by demographic and socioeconomic characteristics, and has become increasingly segregated over time (Figure 13 through Figure 15). As a result of these residential sorting patterns, economic resources remain concentrated in the central portion of the region, and many lower-income residents are being pushed out into southern suburbs. This pattern is noted by Powell (2008), who describes a process of 'extrajurisdictional gentrification' occurring within the Seattle region in which low-income residents are pushed out of their respective cities, only to be displaced to other municipalities that have declining resources and growing needs.

The residential segregation being experienced in the region "both reflects and reinforces social inequalities" (Dwyer 2010, p. 114). This finding is consistent with a national pattern of socioeconomic segregation, caused mostly by income inequality (Chapple 2014; Dwyer 2010; Fischer et al. 2004). As described by Chapple (2014), "Income inequality leads to income segregation because higher incomes, supported by housing policy, allow certain households to sort themselves according to their preferences – and control local political processes that perpetuate exclusion" (p. 64).

Analysis of the regional growth centers also highlights areas where the promise of a centers-based strategy has not been met. Vision 2040 calls for the region to focus future housing and employment growth within regionally designated centers, which are identified as a key element to meeting the regional growth strategy. These centers are intended to develop with a broad range of housing choices, and enable residents of a range of incomes to have easy access
to employment, education and other opportunities. These principles are consistent with Smart
Growth ideas of redistribution (Fincher and Iverson 2008).

Yet, like Dierwechter (2014), I find Smart Growth "reshaping Greater Seattle in
geographically variegated ways" (p. 709). Neighborhood changes within regional growth clusters
show a number of different patterns. A limited number of growth centers exhibited an increase
in the diversity of cluster types comprising the centers, a pattern that would be consistent with
increases in economic diversity (Chapple 2014) and, therefore, relative success of Smart Growth
policies emphasizing greater inclusion. Of the 27 regional clusters examined, 6 show signs of
growing diversity (Lynnwood, Puyallup Downtown, Puyallup South Hill, Seattle Northgate,
Seattle University and Tukwila as shown in Figure 16). The remaining 21 regional growth centers
show either a consistent pattern without neighborhood change (7 centers), or show a reduction
in the diversity of different cluster types comprising the center, in which centers become more
homogenous over time (14 centers). This is consistent with findings from Galster et al. (2008)
who found an overall decline in neighborhood income diversity when studying changes in the
100 largest metropolitan areas.

While neighborhoods can be slow to change (Chapple 2014; Delmelle 2015; Wei and
Knox 2015), reflecting a lag between implementation of planning policies and changes in long-
term outcomes, it appears that the regional growth centers are not yet serving their role as
planned places where a greater range of integration is occurring. While some centers exhibited
signs of increased integration, others did not. Perhaps more troublesome, some of the fastest
growing centers, where the lag time period appears to be less, are experiencing the impacts of
gentrification, a process of exclusion that limits low-income and minority access to opportunity.
Coupled with the 'Back to Downtown' movement taking place in the region, I find there is

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potential for some urban growth centers to result in homogenous, wealthy communities that promote gentrification, consistent with other researchers (Abel and White 2011, 2015; Dierwechter 2008, 2014).

These findings would suggest that increasing housing costs and displacement, key concerns of minority and low-income residents, have become a reality. As noted in a case study of Vision 2040 completed by the U.S. Department of Housing and Urban Development (2015),

One consequence of [the region's] growth, however, has been the rising cost of housing, which has forced families to move farther away from jobs, transit, and other amenities; Seattle’s real (inflation-adjusted) housing prices increased by 20.6 percent from 1998 to 2012.

Displacement has been documented in a number of media reports (Balk 2015, Burger 2015; Green 2016 to name a few) with particular pressures placed on areas with good accessibility and aesthetic amenities.

PSRC appears to be taking initial action to reconsider its Vision 2040 center strategy to more specifically address issues of social equity. Since adoption in 2008, focus has turned to implementation, performance monitoring, and refinement. As part of recommendations stemming from a 2002 Growth Centers monitoring report and included as policies in Vision 2040, PSRC adopted minimum criteria for designating regional growth centers in 2003 and updated them in 2011. Though these criteria were established after many of the centers had been designated, PSRC instituted a center subarea planning requirement that triggers the need for jurisdictions to create a specific center plan, if one has not already been adopted, that would address the requirements of these criteria. Center subarea plans were expected to be completed in 2015. A certification review of plans was required, using the criteria checklist. These criteria include minimum growth targets, mix of uses, compact size and shape, block size and
transportation network requirements. PSRC also encourages jurisdictions to include provisions for affordable housing for all major household income categories (PSRC 2014). In a 2013 review of urban growth centers, PSRC identified that most of the local planning documents for centers lacked specific measures addressing affordable housing (PSRC 2014).

As of 2016, PSRC has initiated a new planning effort aimed at updating the current *Vision 2040* Centers framework, and is considering new procedures for new center designation as well as re-designation of existing regional centers into the new framework. This work continues; adoption of new procedures and re-designation of regional growth centers is anticipated to occur in Fall 2016. Yet, in a background document prepared for the planning effort, there are several changes being considered that suggest potential new policy approaches. First, the background report acknowledges a lack of attention to issues such as social equity and the environment, stating:

There are neither policy guidelines nor a defined board process to discuss the strategic value or regional impacts of particular regional designations, including issues such as the total number of regional centers, their distribution in the region, or their impact on measures such as social equity and the environment. (PSRC 2016, p. 86).

The PSRC Executive Board has prioritized equity issues among the top three concerns to be addressed in the update process.

### 5.2. Air Pollution Exposure

Another key claim associated with the regional growth strategy adopted in *Vision 2040* is that directing development towards urban centers reduces the concentration of air pollutants within the region. This is based on research that has shown a relationship between compact, mixed-use design and reduced travel by motor vehicles, a key source of air pollutants. While the EIS analysis did identify the potential for localized impacts to air quality related to congestion, in
balance it was determined that the impacts could either be mitigated or were offset by benefits, such as low-income and minority increased access to opportunity in regional growth centers, increased physical activity from walkability in regional growth centers, and overall regional emissions reductions. Human-health impacts associated with exposure to toxic and hazardous materials were also evaluated, and it was determined that there were not substantial differences between compact development and dispersed growth.

Analysis at the regional level would suggest that implementation of Smart Growth strategies have resulted in positive outcomes. The number of daily vehicles miles travelled per person by automobile has declined to 1980s levels, allowing total vehicle miles travelled in the region to remain stable over time, despite increases in population and job growth (PSRC 2016). Transit ridership is outpacing employment and population growth (PSRC 2016). The number of 'Good' air quality days, represented by the Air Quality Index, remains high and has increased since 1990, with most days in the good category (PSCAA 2014). Further, the region continues to report either none or a limited number of unhealthy air days, which is the monitoring measure used to evaluate air quality outcomes from Vision 2040.

However, my analysis at a more granular level reveals that exposure impacts predicted in the EIS to vary across the region 'at the microscale' (Sandlin 2005) have materialized, resulting in unequal exposure and a skewed riskscape. Over time, industrial pollution has concentrated into an area encompassing the core of Seattle and parts of Tukwila and Burien to the south, representing 11.8 percent of the region's census tracts, but containing over 56 percent of the toxic concentration associated with large-scale industrial activities. This finding is similar to the results from research by Abel and White (2011, 2015), in their study of Seattle's environmental riskscape. These studies, which focused on the Seattle city limits, found a convergence between
the riskiest industrial facilities and the most socially vulnerable populations. Scaled up to the region, I observe the same patterns emerge: the region deindustrializes over time, with a reduction in the number of large-scale pollution sources and total amount of pollution, but the remaining burdens, in particular industrial-facilities with high-risk emissions, concentrate in South Seattle in the Duwamish and North Tukwila Manufacturing Industrial Centers. The modeled toxic concentration from these facilities, which comprises the riskscape, has therefore become skewed, with a few high emitters concentrating the risk into a small geographic area of the region. Moreover, my statistical analysis reveals that the skewed distribution of exposure risk falls disproportionately on Struggling communities that have higher proportions of minorities, immigrants, and low-income residents.

This study also extends the work by Abel and White by examining other environmental hazards, including ambient sources and small-scale point sources. These sources show an even smaller area of spatial concentration of the greatest impacts. Overall risk exposure, comprising both ambient and point-source exposure risk, is concentrating in 19 census tracts located in Central and South Seattle, where centers of employment, heavy industry and goods-transportation, and traffic congestion all converge. This finding clearly supports Sandlin's (2005) prediction of skewed risksapes 'at the microscale'. In contrast to the focus on industrial emitters, the cumulative analysis does not reveal the same pattern of distributional inequity among neighborhood types, instead showing that there is no statistically significant difference in the cumulative exposure risk among neighborhood types located within the region's cumulative exposure hotspot.

PSRC appears to be reconsidering how its policies impact environmental equity. PSRC has adopted criteria for designating manufacturing industrial areas. These criteria, which were
established after initial designation of the eight centers, includes provisions focusing on minimum employment targets, land planned specifically for industrial and/or manufacturing uses, protection from incompatible land uses (e.g., residential, retail or office uses), efficient size and shape, planning for transportation facilities and services, and urban design standards. In particular, the most recent designation criteria, adopted in 2011, include the following two criteria of relevance:

- Include or reference policies and programs to reduce air pollution and greenhouse gas emissions.
- Establish design standards that help mitigate aesthetic and other impacts of manufacturing and industrial activities both within the center and on adjacent areas (PSRC 2011, p. 4).

PSRC conducted a preliminary evaluation of plans for manufacturing industrial centers to examine the extent to which the plans address topics in this criteria checklist (PSRC 2013). This initial evaluation identified that some jurisdictions had taken steps to address the criteria (Frederickson, Tukwila, Tacoma, Everett, and Bremerton) by having policies in place that address landscaping, clustered development, and other provisions to mitigate industrial impacts to neighboring land uses and, in some cases, multimodal policies aimed at reducing automobile traffic. Notably, both the Ballard-Interbay and Duwamish MICs do not have similar provisions — as a result, there are no provisions in place to buffer neighboring uses from industrial impacts. In addition, PSRC criticized these plans for a lack of strong attention to air quality. Thus, the mitigation measures that were identified in the EIS as needed to offset pollution concentration associated with compact development have not been consistently incorporated into plans or zoning codes for manufacturing industrial centers (PSRC 2013).
In 2015, PSRC undertook a monitoring effort of its industrial lands supply and demand strategy in order to assess whether the region has an adequate and appropriate supply of industrial land and to identify industrial land planning issues that should be addressed. This PSRC report contains a section addressing issues of environmental justice, including maps that compare the location of industrial lands to areas of more concentrated minority and low-income populations, finding that "minority populations may have a high likelihood of living near industrial lands" (p. 3-44). Despite this finding, the report contains no recommendations for mitigation, noting that

Living near industrial lands could have both advantages and disadvantages. On one hand, living near industrial land could result in exposure to negative environmental effects such as noise, glare, dust, and odors. On the other hand, living near industrial land could also provide close access to job opportunities (PSRC 2015, p. 3-44).

The study concludes with a recommendation for more study to "identify potential effects to environmental justice populations, as well as strategies to mitigate effects and increase benefits" (pg. 3-44).

The findings of this study suggest a pattern of inequitable development in the region, raised as a potential in the Vision 2040 EIS and becoming a reality due to policy actions and inactions. Despite these inequalities, mitigation measures have not consistently been implemented across the region.

5.3. **Health Outcomes**

Finally, the claim was made that the regional growth strategy, with its emphasis on an urban centers-based development strategy, would ensure that all residents of the region, regardless of social or economic status, live in a healthy environment. PSRC chose to monitor health outcomes of Vision 2040 through analysis of Body Mass Index (BMI), reflective of the
key concern about the relationship between mixed-used, compact development, active transportation and obesity. Though longitudinal data for BMI is not available, the Washington State Tracking Network, part of the Washington State Department of Health's data, has compiled BMI data for each census tract across Washington state, based on driver's license record information (Washington Tracking Network 2015). Again, the data, which indicate that regional BMI for drivers is lower than the statewide average (Table 23), would seem to support a successful outcome from the Smart Growth policies.

Table 23: Body Mass Index (BMI) for Ages 20+ and 16-19, 2014

<table>
<thead>
<tr>
<th></th>
<th>Average BMI, Age 20+</th>
<th>Average BMI, Ages 16-19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Puget Sound Region</td>
<td>25.92</td>
<td>22.71</td>
</tr>
<tr>
<td>Washington State</td>
<td>26.32</td>
<td>22.94</td>
</tr>
</tbody>
</table>

Yet, a focus on BMI overlooks other health impacts that may be occurring, impacts that are also linked with the built environment and thus are impacted by planning decisions. Asthma hospitalization was evaluated for my study, and the results show that health disparities exist, with socially vulnerable populations at greatest risk. Asthma hospitalization rates are increasing, and are higher in Struggling clusters. Moreover, both socioeconomic status and exposure are statistically associated with asthma hospitalization rates (Table 20). Though there is no specific causal explanation, lower socioeconomic status can be associated with deteriorating housing stock, crowded housing conditions, access to preventative health care, and other stressors, while exposure can be associated with location near highways and industrial areas (Adler and Newman 2002; Braverman et al. 2011; Ludwig et al. 2013).
5.4. Summary

Puget Sound Regional Council is in a unique position to influence equity outcomes – it is one of the few regional organizations that has policymaking authority for economic development, transportation, and land use planning. Vision 2040, one of its key blueprint documents that help to coordinate these responsibilities, was, in many respects, ahead of its time in providing a holistic vision for the region's future the integrated people, prosperity and the planet. Vision 2040’s growth strategy was based on emerging planning concepts addressing healthy cities, and incorporated health outcomes as key goals and monitoring measures of plan implementation. Vision 2040’s approval process also made efforts to create an inclusive atmosphere by reaching out to communities that have been traditionally disenfranchised in planning processes. Further, the environmental review process addressed issues such as environmental health that in many cases are left out of planning decisions. Finally, the region has developed tools to assist its member jurisdictions in promoting public health, social equity, and sustainability.

Since adoption, many of the measures used to monitor implementation performance show positive signs. The region has emerged from the recession with substantial growth in the employment sector; new housing is increasingly being directed to regional growth centers; housing has remained affordable for the median home buyer; alternative modes of travel are increasing and vehicle miles travelled have remained constant; and air quality and health indicators appear positive.

At the same time, there appear to be shortfalls in this Smart Growth-based planning program. PSRC recently completed an assessment of housing fairness and identified a number of patterns of inequity in the region that are limiting access to opportunity for low-income,
foreign-born and American Indian, Hispanic, and African American residents (PSRC 2014). Further, while environmental justice analysis for recent transportation plans and programs concluded that the region's planned transportation investments have equitably benefited minority and low-income households (PSRC n.d.), the *Fair Housing Assessment* has countered that disparities in mobility, economic health, education and public health continue to exist, suggesting that recent planning efforts have been unable to overcome historical patterns of disadvantage (PSRC 2014).

This study supports and extends these findings, identifying economic inequality and segregation patterns within the region that are linked with unequal exposure risk and health disparities. While the region overall has a moderate level of residential segregation as compared to other metro areas, based upon the dissimilarity index (PSRC 2014), spatially there are very clear areas of concentration in southeast Seattle, south King County, Tacoma, and, to a lesser degree east King County and along the I-5 corridor in Snohomish County (PSRC 2014, as well as Figures B-3 through B-5 in Appendix B). These patterns, present in 1990, are rooted in the historical development of the region, and have not been overcome in the over 20 years since adoption of Smart Growth policies in the regional growth strategy. Over time, growing economic inequality has further entrenched these patterns and led to expansion of the geographic scope of Struggling communities. The economic and racially segregated landscape, combined with an increasingly skewed environmental riskscape formed by the contraction of industrial development and subsequent concentration of multiple sources of pollution in areas surrounding South Seattle, has contributed, in part, to growing health disparities in the region.
Chapter 6. Conclusions

The overall purpose of this study was to examine the social equity, environmental exposure, and health outcomes after implementation of the Central Puget Sound region's Smart Growth regional planning framework. The main research questions driving this research were: How have the region's socioeconomic outcomes changed over time? Do the location, distribution and intensity of environmental hazards in the region result in skewed riskscapes, in which some neighborhoods face disproportionately higher risks? What linkages exist among the socioeconomic status, air pollution distribution, and health outcomes?

To answer these questions, I created neighborhood typologies for three different time periods (1990, 2000, and 2014) to track changes in socioeconomic equality outcomes over time. I further analyzed pollution exposure risk, evaluating unevenness in pollution sources over time as well as cumulative pollution risk. I then assessed how that unevenness translates into skewed environmental risk, and evaluate whether the burdens of that risk are evenly distributed. Finally, I analyzed asthma hospitalization rates to evaluate how changes in socioeconomic status and exposure risk are impacting regional health outcomes.

My analysis addresses gaps in current studies in a number of ways. First, my study included a critical analysis of Smart Growth outcomes, designed to shed light on social, environmental and health outcomes in order to determine whether the benefits of Smart Growth accrue equitably. Second, the data and methods that I used address the limitations of early studies, incorporating modeled data of exposure risk, cumulative exposure risk, and hotspots of exposure. In addition, I incorporated an intersectional approach, using numerous variables as proxies for race, class, and immigrant status to analyze the socio-spatial equality
outcomes, and compare those to environmental exposure. Finally, I incorporated health data to examine health outcomes over time, as well as their relationship with socioeconomics and environmental exposure.

I interrogated the rational claims made in the adoption process for Vision 2040, finding that the region has fallen short of meeting its triple bottom line goals. While Vision 2040 was intended to concentrate development and be a more socially equitable growth alternative than dispersed growth, I found that economic inequality has continued to increase. Over time, more neighborhoods within the region met the Struggling neighborhood classification. Further, the region remains spatially segregated by demographic, race/ethnicity and housing characteristics, with Struggling communities located closer to major roadways, airports, industrial ports, and military bases. Even though Vision 2040 set out to reduce the concentration of air pollutants, I found that while exposure levels are down, consistent with de-industrialization, the remaining exposure risks have spatially consolidated into regionally designated Manufacturing Industrial Centers, particularly those located near south Seattle. As a result, Struggling neighborhoods, which are located in closest proximity to these industrial areas, experience a disproportionately higher exposure risk than other neighborhood types. Finally, while Vision 2040 was intended to ensure that all residents live in a healthy environment, I found that asthma hospitalization rates are increasing, with the highest rates and greatest increases in Struggling neighborhoods.

Further, my study raises concerns about how evidence is weighed and decisions are made when considering exposure and health impacts. In the case of Vision 2040, potential exposure impacts were identified, but overlooked as part of a decision-making process that assumed impacts would be offset by other gains or mitigated. Yet, it appears that neither the
benefits nor mitigation measures have fully materialized. *Vision 2040* has so far failed to mitigate development inequality within the region that is contributing to health disparities.

How does this work respond to the debate over Smart Growth planning outcomes? Ewing and Hamidi (2015) recently set out to revisit the 1997 *Journal of the American Planning Association*’s point-counterpoint articles that examined different arguments for compact growth (Ewing 1997) versus sprawl (Gordan and Richardson 1997), listed by the American Planning Association as a ‘classic’ in urban planning literature. In this article, Ewing and Hamidi reviewed the literature on outcomes, addressing a number of issues, including vehicle miles travelled, traffic congestion, air quality, physical activity and public health, infrastructure costs, housing affordability and racial desegregation, central city decline, and traffic safety. Interestingly, the literature review contains very few critical analysis of compact development, explained by Ewing and Hamidi as follows: "The review is more heavily oriented toward costs of sprawl because the literature itself is more heavily oriented toward costs" (p. 418). This lack of critical attention to the impacts of compact development is telling, as it reflects the continued framing of compact development initiatives like Smart Growth in opposition to sprawl. While Smart Growth has been shown to have better outcomes on many issues as compared to sprawl (Ewing and Hamidi 2015), it is time for Smart Growth's outcomes to be critically examined against its promised benefits so that this planning framework can continue to evolve and become 'smarter'.

Ewing and Hamidi (2015) acknowledge that "…growth management and smart growth initiatives have had, at best, mixed results" (p. 425). My analysis also showed mixed results; with respect to equity outcomes, the results indicated that the region continued to experience development inequality, in which the burdens of Smart Growth initiatives fall disproportionately on communities that with lower incomes and higher proportions of minorities and immigrants.
Struggling communities experienced socioeconomic decline, disproportionately higher exposure to air pollution, and declining health outcomes in comparison to their counterparts. With respect to equity outcomes, Smart Growth as applied in the Puget Sound region has either been ineffective, or has not had sufficient time for positive outcomes to materialize.

My analysis affirms the work of other researchers that suggest that the social equity outcomes are overlooked under Smart Growth planning principles. Patterns of inequitable development and fragmentation that are rooted in prior redlining, suburbanization and urban renewal policies remain and are not ameliorated under a Smart Growth planning regime. Further, my research suggests that the urban form envisioned by Smart Growth exacerbates environmental exposure inequalities. Lack of industrial retention throughout the region, as cities redevelop industrial areas with mixed-use and commercial developments, is consolidating industrial development into specific industrial centers that are increasingly becoming 'sacrifice zones', with the resulting exposure burdens being disproportionately experienced by the region's most Struggling communities. Finally, my research suggests that Smart Growth planning has the potential to exacerbate existing health disparities. Thus, Puget Sound's experience with Smart Growth has potential implications for its application in other localities.

Beyond the debate over Smart Growth, this analysis also engages with other researchers in a larger critique of spatial planning. As previously summarized by Huxley (2008), these critiques can largely be grouped under three different categories:

… perspectives that, while critical of the institutions and practices of planning, suggest possibilities for planning to make a difference for the better; and …perspectives suggesting that planning is severely limited in its ability to effect change – either it has no effects other than to support the status quo or if it has any effects, they are largely negative, exacerbating existing inequalities (p. 126).
In the case of the Puget Sound region, I found evidence of development inequality that bring into question the effectiveness of regional planning and Smart Growth. This inequality is present despite what Benner and Pastor (2015) describe as "prominent race and social justice initiatives [that] have been institutionalized in city, county, and regional planning processes" (p. 187). Whereas I found evidence of social, environmental, and health disparities, Benner and Pastor (2015) conclude that "Seattle has made a remarkable commitment to maintaining equitable opportunity even as it is...subject to the highly disequalizing trends associated with being a center of innovation for the 'new economy'"(p. 73). These seemingly contradictory findings reveal the limitations of planning initiatives like Smart Growth and regionalism. In the case of Puget Sound, despite what Benner and Pastor (2015) identify as the strength of regional efforts to identify and address processes that are driving inequality, the planning tools used (e.g., growth boundaries, infill and redevelopment, focused investments, affordable housing levies, etc.) have been unable to deliver improved outcomes for all residents of the region. My findings, as a result, support Harvey (1985, 1996) and others who contend that planning is severely limited in its ability to effect change.

Why is planning limited? Our communities have long histories of policy actions (or inactions) that have created spatial patterns of opportunity and burden. Yet, regional planning efforts have thus far not paid sufficient attention to the patterns and processes of socioeconomic and racial and ethnic segregation that have left lasting imprints on the region's urban development patterns. As Dierwechter (2015) remarks, "...smart growth cannot and does not 'land' unalloyed; it is adulterated socially, if often surprisingly, by what Lefebvre memorably and elusive called the 'meshwork' of cities" (p. 709). In Puget Sound, existing patterns of income inequality are being reinforced with 'Back to the City' redevelopment, fostered by the growth in
the new economy. New infill and redevelopment has been focused near the core of the region, which has remained whiter and wealthier than the surrounding areas; meanwhile, disadvantaged communities and communities of color remain segregated along major roadways, near military installations and near remaining industrial lands, increasing their exposure and threatening their health.

In order to effect change in equity issues, regional planning has to work at identifying, challenging and transforming existing development patterns and processes that create inequities. As stated by Huxley (2008),

Planning's concerns to produce ordered, healthy, inspiring or empowering environments only serve to mask structural inequalities; and its ambitions for social improvement are doomed to failure, if it does not, at the same time, addresses the structural causes of exploitation or marginalization" (p. 134).

This work is difficult for numerous reasons, including lack of inclusive decision-making, involvement of economic and political interests in planning, and lack of tools. As noted by Benner and Pastor (2015), "Concerns about both equity and growth can become second nature to a particular metro over time—think Seattle—but raising the issues of distributive justice and keeping them raised often requires a fight" (p. 227). Thus, even in regions viewed as more inclusive, equity remains a fight.

The tools available to planners to engage in this fight are currently limited. As stated by Chapple (2014), "...the planner's toolkit of urban growth boundaries, impact fees, redevelopment, and regional transportation funding is, for the most part, ill-equipped to protect social equity" (p. 71). As a result, additional scholarship is needed to develop new strategies, adapted to local conditions and the characteristics and aspirations of the communities that are being planned for. In addition, more critical research into outcomes, paired with praxis, is
needed to re-examine the current limits of planning. Thus, it is unlikely that one solution (such as Smart Growth) will emerge – rather, multiple and varied concepts and strategies are needed to address the variety of conditions and needs and capacities within our regions.

This finding highlights the need for new strategies that seek to address larger institutional and structural barriers to equality. Emerging strategies that may show potential include value capture, preservation of affordable housing, inclusive housing requirements, and community benefits agreements, coupled with other strategies such as workforce development and wealth-building initiatives (Blackwell 2000; Chapple 2014). Adaptation of strategies requires effective participatory democracy to ensure that these strategies are responsive and accountable to communities that have historically been excluded from decision-making but face the greatest burden in terms of inequalities.

This study is limited by a number of issues. First, this study is specific to the Central Puget Sound region during the time period of study, and thus the findings here may not be comparable to other regions implementing Smart Growth policies. Comparative analysis with other regions would be a beneficial area of research, and would be helpful in further engaging in the debate over the equity benefits of Smart Growth planning. Further, this study is conducted at a '30,000 foot view' and therefore lacks analysis at multiple scales. Research by Abel and White (2011 and 2015) as well as Dierwechter (2014) shows the potential to pair this work with additional analysis at multiple scales (e.g., site development, neighborhood or district, city, and region). Geographically weighted regression analysis of social and environmental factors and their impact on health outcomes could highlight potential areas for additional research and potential policy intervention.
In addition, this work is limited by its reliance on quantitative methods. Additional research could extend this preliminary evaluation and pair it with qualitative work that engages the impacted communities identified in this research, as well as policymakers, planners, and health officials engaged with these communities. Further, the quantitative methods used for small source facilities would benefit from additional research – exposure details are not yet available for these facilities and development of models that could estimate exposure would advance the research of impacts from these facilities. Moreover, longitudinal analysis of cumulative impacts is currently limited by available data. Finally, this research used air pollution and asthma hospitalization as the exposure and health outcome indicators; many additional factors (e.g., environmental factors such as water quality, open space and recreational areas, food access and security, and accessibility as well as related health outcomes) should be considered to gain a broader understanding of the impacts of Smart Growth policies.

Smart Growth is increasingly moving beyond its initial fixation with preventing sprawl, and in doing so is maturing to embrace concepts of healthy cities and social equity. It is important that critical research into the outcomes of these planning efforts continue in order to identify potential weaknesses and opportunities for improvement. While place does play a role in shaping our socioeconomic, exposure, and health outcomes, it is important that we continue to strive to improve this landscape, expanding opportunities and community resources to ensure that everyone has what they need to be successful.
Glossary of Terms

**Environmental hazard:** A threat to people and their valuables (Cutter et al 2003). As used here, a dangerous phenomenon, substance, human activity or condition that may cause loss of life, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

**Environmental inequality:** Occurs when the costs of environmental risk, and the benefits of good environmental policy, are not shared fairly across the demographic and geographic spectrums (Schlossberg 2007).

**Environmental inequality formation:** Occurs when different stakeholders struggle for access to scarce resources within the political economy, and the benefits and costs of those resources become distributed unevenly (Pellow 2000).

**Environmental injustice:** Occurs when a particular social group is burdened with environmental hazards (Pellow 2000).

**Environmental justice:** 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 (EPA). (Note: Environmental Justice (EJ) is not universally defined. EJ has different meanings to various communities and institutions).

**Environmental racism:** As originally used, it referred to racial discrimination in environmental policy-making and enforcement of regulations and laws and the deliberate targeting of communities of color for toxic waste facilities. This term has evolved with under
work by Pulido (1996, 2000) and others to address historical processes of racial formation and acknowledge that diverse forms of racism emerge in different places, and at different scales.

**Environmental risk:** Chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental hazard, such as exposure to hazardous chemicals (EPA).

**Environmental riskscape:** Spatial variation in environmental risks and potential vulnerability to environmental hazards (Morello-Frosch et al 2001).

**Equality:** Fair and equal distribution of benefits and costs.

**Equity:** Ensuring that everyone has what they need to be successful.

**Exposure:** Contact of a person with the air pollutant of concern.

**Healthy Cities:** City that is continually creating and improving those physical and social environments and expanding those community resources which enable people to mutually support each other in performing all the functions of life and developing to their maximum potential (WHO 1998).

**Neighborhood:** Geographic unit with multiple attributes, such as race, socioeconomic status, age, etc. As used here, census geographies such as census block groups or census tracts is used as proxies for neighborhoods. All attributes are analyzed using the same geographic scale.

**Scale of Analysis:** The Urban Growth Boundary for the Central Puget Sound region.
**Unit of Analysis:** For neighborhood typology, either census block groups or census tracts, depending on the availability of data. For Toxic Release Inventory and RSEI, point source data.


### Appendix A: Variables in Principal Component Analysis

<table>
<thead>
<tr>
<th>Variables</th>
<th>1990 Census Variable #</th>
<th>2000 Census Variable #</th>
<th>2010-2014 ACS Variable #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Population</td>
<td>P0010001</td>
<td>P001001</td>
<td>B01003 VD01</td>
</tr>
<tr>
<td>% Population Age 25-34</td>
<td>P0130018 + P0130019 (Out of P0010001)</td>
<td>P008026 + P008027 + P008065 + P008066 (Out of P008001)</td>
<td>B01001 VD11 + VD12 + VD35 + VD36 (Out of VD01)</td>
</tr>
<tr>
<td>% Population White alone</td>
<td>P0120001</td>
<td>P007003</td>
<td>B03002 VD03</td>
</tr>
<tr>
<td>% Population African American alone</td>
<td>P0120002</td>
<td>P007004</td>
<td>B03002 VD04</td>
</tr>
<tr>
<td>% Population Asian alone</td>
<td>P0120004 Note: Asian/Pacific</td>
<td>P007006</td>
<td>B03002 VD 06</td>
</tr>
<tr>
<td>% Population Latino/Hispanic²⁰</td>
<td>Compare P0100001 with P0120006 + P0120007 + P0120008 + P0120009 + P0120010</td>
<td>P007010</td>
<td>B03002 VD12</td>
</tr>
<tr>
<td>% Foreign Born</td>
<td>P0420009</td>
<td>P021013 (OUT OF P021001)</td>
<td>B99052 VD05 + VD06</td>
</tr>
<tr>
<td>% Linguistically isolated</td>
<td>P0290002 + P0290004 + P0290006</td>
<td>P020004 + P020007 + P020010 + P020013 (OUT OF P020001)</td>
<td>B16002 VD04 + VD07 + VD10 + VD13</td>
</tr>
<tr>
<td><strong>Socioeconomic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Persons over 24 with College Education</td>
<td>P0570006 + P0570007 (OUT OF P057)</td>
<td>P037015 + P037016 + P037017 + P037018 + P037032 + P037033 + P037034 + P037035 (OUT OF P037001)</td>
<td>B15003 VD22 + VD23 + VD24 + VD25 (out of VD01)¹</td>
</tr>
<tr>
<td>% Unemployed</td>
<td>P07000003 + P07000007 (civilian)</td>
<td>P0430007 + P0430014 (civilian unemployed)</td>
<td>B23025 VD04 (EMPLOYED) - VD05</td>
</tr>
</tbody>
</table>

²⁰The 1990 estimates for race are not directly comparable to 2000 and 2010 estimates due to changes in race categories on the Census questionnaire. Starting in 2000, respondents were given the option to report more than one race. In addition, the question about ethnicity was moved to precede the race question. These changes may affect comparability of 1990 estimates on Hispanic/Latino ethnicity with estimates from 2000 and 2010. Despite this, researchers completing longitudinal studies have included this variable in their analysis (Mikelbank 2011; Wei and Knox 2014).
<table>
<thead>
<tr>
<th>Variables</th>
<th>1990 Census Variable #</th>
<th>2000 Census Variable #</th>
<th>2010-2014 ACS Variable #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unemployed</strong></td>
<td>unemployed) (OUT OF P070002 + P070003 + P070006 + P070007) (civilian in labor force)</td>
<td>(out of P043005 + P043012)</td>
<td>(UNEMPLOYED) OUT OF VD01 (TOTAL OVER 16)</td>
</tr>
<tr>
<td>% Managerial/Professional</td>
<td>P0770016</td>
<td>P049017 + P049044</td>
<td>B23025 VD17 + VD47</td>
</tr>
<tr>
<td>Median household income</td>
<td>P080A001</td>
<td>P053001</td>
<td>B19013</td>
</tr>
<tr>
<td>% Below Poverty Line</td>
<td>P1170013 + P1170014 + P1170015 + P1170016 + P1170017 + P1170018 + P1170019 + P1170020 + P1170021 + P1170022 + P1170023 + P1170024</td>
<td>P087002 (OUT OF P087001)</td>
<td>Not in poverty minus B17021 VD02 (OUT OF VD01)</td>
</tr>
</tbody>
</table>

**Housing**

<table>
<thead>
<tr>
<th>Housing Units</th>
<th>H0010001</th>
<th>H001001</th>
<th>B25003</th>
</tr>
</thead>
<tbody>
<tr>
<td>% 2+ Person Non-Family Households</td>
<td>P0170009 + P0170011 + P0170012</td>
<td>P009020 + P009023 + P009024</td>
<td>B25011 VD22 + VD46</td>
</tr>
<tr>
<td>% Owner occupied</td>
<td>H0080001</td>
<td>H007002 (OUT OF H007001 – OCCUPIED UNITS)</td>
<td>B25008 VD02 (out of VD01)</td>
</tr>
<tr>
<td>Median home value</td>
<td>H061A001</td>
<td>H085001</td>
<td>B25077</td>
</tr>
<tr>
<td>Median gross rent</td>
<td>H043A001</td>
<td>H063001</td>
<td>B25064</td>
</tr>
<tr>
<td>% Single parent household with children</td>
<td>P0190003 + P0190005 (out of all P019)</td>
<td>P015010 + P015016 (TOTAL FAMILIES P015001)</td>
<td>B11003 VD02, VD14, VD20 MINUS VD10 + VD16</td>
</tr>
<tr>
<td>Over-crowded housing condition (more than one person per room)</td>
<td>H0690002 + H0690003 + H0690005 + H0690006 + H0690008 + H0690009 + H0690011 + H0690012</td>
<td>H020005 + h020006 + H020007 + H020011 + H020012 + H020013 (OUT OF h020001)</td>
<td>B25014 VD03,4,9,10 MINUS VD05 THRU VD07 + VD11 THRU VD13</td>
</tr>
</tbody>
</table>
Appendix B: Principal Components Analysis Results

This Appendix contains detailed results for the principal components analysis (PCA). The PCA indicates a three-factor solution of socioeconomic status, racial polarization, and household structure as the underlying dimensions of the 18 different variables used to examine neighborhood characteristics in the Central Puget Sound region (Table B-1). This three-factor solution is similar to results from classical factorial ecology (Berry and Kasarda 1977; Burgess 1925; Hoyt 1939; Murdie 1969; Park 1952; and others as referenced in White 2012).

Before accepting the three-factor solution, the results of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) measure and the Bartlett’s Test of Sphericity (Bartlett’s) were reviewed to ensure that the dataset was appropriate to evaluate with a Principal Components Analysis. The KMO result was 0.821, above the suggested minimum of 0.6 (Field 2009) and near the high value of 1, which indicates that patterns of correlations are relatively compact and, as a result, a PCA should yield distinct and reliable factors. In addition, the anti-image correlation was evaluated, and all values were higher than the desired minimum value of 0.5 (Field 2009). The Bartlett's test was highly significant (p < .001), indicating that the correlations in the dataset are big enough to make the PCA analysis meaningful (Field 2009).

A three-factor solution was derived by examining the eigenvalues to determine if the values are large enough to represent a meaningful factor; this was done through evaluation of a scree plot, which plots each eigenvalue against the factor with which it is associated (Figure B-1). Three factors were identified with eigenvalues greater than one, a common threshold for determining how many factors to retain in the analysis (Field 2009). In this case, each factor
retained has an eigenvalue of at least 2. A review of the communalities output indicates that the resulting communalities (after extraction) are greater than 0.5, except for the percent Latino and percent home ownership variables; as a result, the factors provide a reasonable explanation of the variance in the original data (Field 2009).

Figure B-1: Scree Plot depicting the eigenvalue plotted against the factors retained in the Principal Components Analysis

The three-factor solution explained over 67% of the total variance. Component 1, which highlights differences in socioeconomic status, explains over 28% of the variance alone. Variables on this component with high loadings include percentage of college-educated adults, median house value, median household income, median gross rent, and proportion employed in professional or managerial occupations. These variables exhibit a positive component loading,
and they are in stark contrast to the variables that had a negative loading, including proportion of single-headed households, percentage unemployed, percentage in poverty status, and percentage living in overcrowded housing conditions. Figure B-1 shows this opposition between positively and negatively loaded variables in a 3-D projection. In the graph, the orange circles represent the variables comprising the socioeconomic status component (Component 1), with variables radiating out from a starting point of zero; positive loadings radiate out to the right, corresponding with higher component scores, and negative loadings radiate out toward the left, corresponding with lower component scores.

Component 2, which highlights differences in racial and ethnicity mixing or segregation, explains 26% of the variance. Variables on this component with high loadings include percentage foreign born, proportion of Asian residents, proportion linguistically isolated, and proportion of African American residents. These variables exhibit a positive component loading, and are in stark contrast to proportion of White residents, which had a negative loading. Figure B-2, which depicts variables in this component in green, again highlights the opposition of these variables within Component 2.

Component 3, which highlights differences in household structure, explains over 13% of the variance. Variables on this component with high loadings include percentage of the population age 25-34 years-old, together with non-family households. These variables exhibit a positive component loading. Figure B-2 highlights these positively loaded variables in yellow.
Figure B-2: PCA Component 3-D Plot
### Table B-1: Results of Principal Components Analysis, all years (1990 - 2010)

<table>
<thead>
<tr>
<th>Category and Variable Name</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Socioeconomic Status</td>
</tr>
<tr>
<td><strong>Population</strong></td>
<td></td>
</tr>
<tr>
<td>Population Age 25-34</td>
<td></td>
</tr>
<tr>
<td>Percent White Alone</td>
<td></td>
</tr>
<tr>
<td>Percent African American Alone</td>
<td></td>
</tr>
<tr>
<td>Percent Asian Alone</td>
<td></td>
</tr>
<tr>
<td>Percent Latino</td>
<td></td>
</tr>
<tr>
<td>Percent Foreign Born</td>
<td></td>
</tr>
<tr>
<td>Linguistically Isolated</td>
<td></td>
</tr>
<tr>
<td><strong>Socioeconomic</strong></td>
<td></td>
</tr>
<tr>
<td>College Graduates</td>
<td>.884</td>
</tr>
<tr>
<td>Professional/Managerial</td>
<td>.621</td>
</tr>
<tr>
<td>Median Household Income</td>
<td>.810</td>
</tr>
<tr>
<td>Income Poverty</td>
<td>-.584</td>
</tr>
<tr>
<td>Unemployed</td>
<td>-.635</td>
</tr>
<tr>
<td><strong>Housing</strong></td>
<td></td>
</tr>
<tr>
<td>2+ Person Non-Family Houses</td>
<td>.857</td>
</tr>
<tr>
<td>Single-Parent Households</td>
<td>-.677</td>
</tr>
<tr>
<td>Overcrowded Housing</td>
<td>-.526</td>
</tr>
<tr>
<td>Median Gross Rent</td>
<td>.716</td>
</tr>
<tr>
<td>Median House Value</td>
<td>.836</td>
</tr>
<tr>
<td>Owner-occupied</td>
<td></td>
</tr>
<tr>
<td><strong>Percent Variance</strong></td>
<td>28.3%</td>
</tr>
<tr>
<td><strong>Cumulative Variance</strong></td>
<td>28.3%</td>
</tr>
</tbody>
</table>

Notes: Loadings -0.50 to +0.50 not shown. Varimax rotation with Kaiser normalization.

The spatial distribution of the component scores was then evaluated for the three time periods: 1990, 2000, and 2010 with the results provided in Figure B-3 through Figure B-5, respectively. These figures show the spatial patterns associated with Component 1, Socioeconomic Status, with darker shades of orange indicating higher component scores, and correspondingly higher rates of income, house value, proportion of college graduates and
professional and managerial professions. The maps reveal a clear pattern of spatial segregation by socioeconomic status that exists within the Central Puget Sound region. Residents with relatively greater socioeconomic status are located in a pattern radiating out east and west from Seattle's Central Business District, including Bainbridge Island to the west, and Mercer Island, Medina, Clyde Hill, Hunts Point, Yarrow Point, Bellevue, Redmond, Kirkland, Sammamish and Issaquah to the east. These communities are located within commuting distance to Seattle, and contain lake and mountain views, open space, and other amenities that make these communities attractive places to live.

In contrast, the areas with relatively lower socioeconomic status (shown in lighter colors) have lower component scores, indicating lower rates of income, house value, proportion of college graduates and professional and managerial professions and higher rates of single-parent headed households, poverty, unemployment, and overcrowded housing conditions. These areas are concentrated in south King County, Pierce County, and north Snohomish County.

This overall pattern holds from 1990 through to 2010, though there are some areas that experience relative upgrading and downgrading in socioeconomic status. Most notably, the South Lake Union area of Seattle transforms from an area of relatively lower socioeconomic status to an area of relatively higher socioeconomic status, a trend observed by other researchers who have studied the impacts of gentrification in the City of Seattle (Abel et al 2016). In contrast, communities in south King County located along the I-5 corridor, such as Tukwila, SeaTac and Kent show a relative decrease in socioeconomic status from 1990 to 2010. The same pattern is also apparent in north Snohomish County, where the communities of Marysville and Arlington show a relative decrease in socioeconomic status over the same time frame. The
patterns appear to reflect the observations by Morrill (2014d), who analyzed income inequality in the Central Puget Sound area and concluded that

areas of greater local economic and social diversity exhibit higher inequality, while more homogenous areas, dominated by single-family homes across the spectrum from poor to rich, are less unequal in their income distributions (n.p.).
Figure B-3: Factor Scores on Component 1, 1990

Appendix B: 8
Figure B-4: Factor Scores on Component 1, 2000

Projection: NAD 1983 StatePlane Washington North FIPS 4601 Feet
Data Sources: GeoLytics, Puget Sound Region Council, ESRI
Prepared by: Stacy Clauson
Date: May 16, 2016

Appendix B: 9
Figure B-5: Factor Scores on Component 1, 2010
The second component revealed a similar spatial pattern of racial and ethnic segregation in the Central Puget Sound Region. Figure B-6 through Figure B-8 show the spatial patterns associated with Component 2, Racial Polarization, with darker shades of green indicating higher component scores, and correspondingly higher proportions of racial and ethnic minorities. The maps reveal a clear pattern of spatial segregation by race and ethnicity, but one that has changed substantially over time. In 1990, ethnic and racial minorities were concentrated in parts of south Seattle, south Tacoma, and near the Air Force base in south Pierce County. This distribution was, in part, an artifact from a history of racial restrictive covenants and redlining that existed in the region, which concentrated African Americans and Asians in central and south Seattle and into suburbs located south of the city (Morrill 1995 and Silva 2009).

By 2010, racial and ethnic minorities were prominent in more areas throughout the region, but the overall pattern is still spatially segregated, with concentration of racial and ethnic minorities in southeast Seattle, south King County, south Tacoma, along the I-5 corridor in Snohomish County, and in east King County, largely due to an influx of Asian residents, as depicted in Appendix B and by Morrill (2011c). This pattern of racial concentration is consistent with patterns observed by Morrill (2011c) in his analysis of 2010 US Census results for the Seattle-metro area. Morrill observed a lack of diversity in Seattle, as redistribution of minority populations has occurred largely outside of the City, mainly in areas south of the City, which have become more remarkably more diverse. Morrill (2011c) states:

The main story from the census findings is the continued gentrification of Seattle, with displacement of minorities and the less affluent out of the center of the city, especially to south King county and Pierce county. The city core is becoming whiter, while the edges and suburbs, north and east as well as south are becoming far more diverse (n.p.)
Similar findings related to diversity are contained in the regional Fair Housing Equity Assessment completed by Puget Sound Regional Council (2014).

In his analysis, Morrill (2011b) notes that the reasons for the minority redistribution are complex, but notes that

..the popularity of living in Seattle on the part of younger, less familial and more professional households, together with shifts in the housing stock away from family housing, was critical in making the central city less diverse and the rest of the region, and much of the state, more so (n.p).

The comments by Morrill suggest that regional Smart Growth planning has had an impact on spatial patterns of neighborhood structure and change within the region.
Figure B-6: Facto Scores on Component 2, 1990
Figure B-7: Factor Scores on Component 2, 2000
Figure B-8: Factor Scores on Component 2, 2010
The third component reveals a new trend that has emerged over time, the segregation of single, young, non-family households into distinct neighborhoods within the region. Figure B-9 through Figure B-11 first show the spatial patterns associated with Component 3, Household Structure, with darker shades of yellow indicating higher component scores, and correspondingly higher proportions of non-traditional households composed of non-family households with residents aged 25 to 34 years old. More urbanized areas, such as Seattle and Tacoma have long exhibited this trait, exhibiting a different demographic characteristic than surrounding family-oriented suburban neighborhoods. Yet, this trend intensifies between 1990 and 2010, with a starker contrast in high and low-component loadings emerging in the 2010 time period. This pattern of household structure is consistent with patterns observed by Morrill (2011e) in his analysis of 2010 US Census results for the Seattle-metro area, who observed a regional sorting of different household types: traditional husband-wife families with children reside in suburban and exurban tracts, married without children are high in amenity retirement areas, single-parent households are generally poor and many are minority, with high proportion residing in South Seattle through south King County, and through much of Tacoma and Pierce County; while shares of unmarried partner households (the key demographic highlighted by this component) are particularly prevalent in the City of Seattle, but also in less affluent areas and in areas with a high minority population. As stated by Morrill (2011e): "[Increases in families without children] seem to be related to gentrification, most obviously in the historic [Central District] and Southeast Seattle, but also in some northern neighborhoods" (n.p.) These would include areas around South Lake Union, Interbay, and Green Lake in Seattle, which have all experienced substantial redevelopment in the last decade.
Figure B-9: Factor Scores on Component 3, 1990
Figure B-10: Factor Scores on Component 3, 2000
Figure B-11: Factor Scores on Component 3, 2010
Appendix C: Hierarchical Clustering Results

This Appendix contains detailed results for the hierarchical clustering analysis. The hierarchical cluster analysis of the three components revealed a 9-cluster solution. In order to determine the appropriate number of clusters, two different analysis were completed: 1) analysis of the coefficients reported in the agglomeration schedule to identify stages where large difference between the coefficients emerge, suggesting that the clusters being merged are increasing in heterogeneity; and 2) analysis of the clustergram results to visualize how the members of the clusters are formed as the number of clusters increase (Schonlau 2002; Wei 2013; Wei and Knox 2014). Figure C-1 plots the coefficients against the agglomeration stages; the results reveal the start of substantial changes in coefficient values between stages 2195 and 2200, pointing toward a 9-cluster solution.
These results were confirmed by analyzing the clustergram results, which revealed that the final two clusters that diverged to form the 9-cluster solution (the Struggling Working Class and Low-Income and Non-Traditional Household described below) have distinct differences that warranted division into two separate clusters. A 3-D scatterplot of the component scores plotted by the resulting 9-clusters reveals distinct patterns of agglomeration and separation (Figure C-2). This figure reveals how the components derived in the Principal Components Analysis form the basis for the cluster breaks: for example, the Young, Single, Educated and Mobile renters depicted in yellow have relatively high rates of non-traditional household structure, combined with high socioeconomic status and low racial integration; the Disadvantaged Racial/Ethnic Minority Enclave depicted in dark brown have different and high rates of racial integration, and also have relatively lower socioeconomic status; and the Old City
Establishment depicted in dark blue have higher socioeconomic status than other clusters, is not racially integrated and is comprised of households with a traditional family structure.

Figure C-2: 3-D Scatterplot of Principal Component Scores Plotted by Cluster

A basic breakdown of the estimated population contained in each cluster is detailed in Table C-1.
<table>
<thead>
<tr>
<th>Cluster</th>
<th>1990 Pop</th>
<th>% 1990 Pop</th>
<th>2000 Pop</th>
<th>% 2000 Pop</th>
<th>2010 Pop</th>
<th>% 2010 Pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old City Establishment</td>
<td>303,037</td>
<td>13.0%</td>
<td>325,211</td>
<td>12.1%</td>
<td>393,582</td>
<td>12.5%</td>
</tr>
<tr>
<td>Middle Class Suburbs</td>
<td>260,822</td>
<td>11.2%</td>
<td>177,706</td>
<td>6.6%</td>
<td>270,919</td>
<td>8.6%</td>
</tr>
<tr>
<td>Family Suburban Homeowners</td>
<td>658,668</td>
<td>28.3%</td>
<td>591,891</td>
<td>22.0%</td>
<td>668,455</td>
<td>21.2%</td>
</tr>
<tr>
<td>Emerging Middle Class/Asian Influx Suburbs</td>
<td>248,790</td>
<td>10.7%</td>
<td>367,796</td>
<td>13.7%</td>
<td>392,687</td>
<td>12.4%</td>
</tr>
<tr>
<td>Young, Single, Educated and Mobile Renters</td>
<td>71,229</td>
<td>3.1%</td>
<td>162,576</td>
<td>6.1%</td>
<td>133,020</td>
<td>4.2%</td>
</tr>
<tr>
<td>White Working Class Suburbs</td>
<td>427,025</td>
<td>18.3%</td>
<td>495,730</td>
<td>18.5%</td>
<td>543,985</td>
<td>17.2%</td>
</tr>
<tr>
<td>Struggling Working Class Suburbs</td>
<td>164,689</td>
<td>7.1%</td>
<td>224,288</td>
<td>8.4%</td>
<td>308,660</td>
<td>9.8%</td>
</tr>
<tr>
<td>Low-Income Non-Traditional Household</td>
<td>114,928</td>
<td>4.9%</td>
<td>263,506</td>
<td>9.8%</td>
<td>361,386</td>
<td>11.4%</td>
</tr>
<tr>
<td>Disadvantaged Racial/Ethnic Enclave</td>
<td>81,402</td>
<td>3.5%</td>
<td>76,391</td>
<td>2.8%</td>
<td>62,308</td>
<td>1.2%</td>
</tr>
<tr>
<td><strong>Regional Total</strong></td>
<td>2,330,588</td>
<td></td>
<td>2,685,095</td>
<td></td>
<td>3,160,699</td>
<td></td>
</tr>
</tbody>
</table>

*Table C-1: Population Characteristics in Central Puget Sound Neighborhood Clusters*
More detailed characteristics of these clusters are obtained by examining the mean values for each of the study variables. Table C-2 provides an overview of the demographic characteristics. The highest value in each column is highlighted in bold and the lowest in italics, to help identify some of the defining characteristics of each cluster.
<table>
<thead>
<tr>
<th>Cluster</th>
<th>Population Age 25-34</th>
<th>% White Alone</th>
<th>% African American Alone</th>
<th>% Asian Alone</th>
<th>% Latino</th>
<th>% Foreign Born</th>
<th>% Linguistically Isolated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old City Establishment</td>
<td>11.1</td>
<td>82.6</td>
<td>1.4</td>
<td>10.3</td>
<td>2.8</td>
<td>13.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Middle Class Suburbs</td>
<td>18.4</td>
<td>85.3</td>
<td>2.2</td>
<td>5.2</td>
<td>4.0</td>
<td>9.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Family Suburban Homeowners</td>
<td>12.6</td>
<td>81.7</td>
<td>2.9</td>
<td>7.2</td>
<td>4.4</td>
<td>9.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Emerging Middle Class/Asian Influx Suburbs</td>
<td>16.3</td>
<td>64.2</td>
<td>6.8</td>
<td>17.2</td>
<td>6.9</td>
<td>21.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Young, Single, Educated and Mobile Renters</td>
<td>26.5</td>
<td>77.1</td>
<td>5.4</td>
<td>8.5</td>
<td>4.7</td>
<td>12.7</td>
<td>3.3</td>
</tr>
<tr>
<td>White Working Class Suburbs</td>
<td>13.1</td>
<td><strong>85.8</strong></td>
<td>2.2</td>
<td>2.9</td>
<td>4.4</td>
<td>5.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Struggling Working Class Suburbs</td>
<td>16.1</td>
<td>71.4</td>
<td>7.5</td>
<td>4.8</td>
<td>9.2</td>
<td>9.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Low-Income Non-Traditional Household</td>
<td>15.1</td>
<td>48.6</td>
<td>14.9</td>
<td>13.6</td>
<td><strong>15.0</strong></td>
<td>22.6</td>
<td>9.8</td>
</tr>
<tr>
<td>Disadvantaged Racial/Ethnic Enclave</td>
<td>14.6</td>
<td>24.4</td>
<td><strong>23.1</strong></td>
<td>38.9</td>
<td>8.0</td>
<td><strong>38.0</strong></td>
<td>21.0</td>
</tr>
</tbody>
</table>

*Table C-2: Demographic Characteristics in Central Puget Sound Neighborhood Clusters*
Table C-3 provides an overview of the socioeconomic characteristics.

**Table C-3: Socioeconomic Characteristics in Central Puget Sound Neighborhood Clusters**

<table>
<thead>
<tr>
<th>Cluster</th>
<th>% College Graduates</th>
<th>% Professional/Managerial Occupations</th>
<th>Median Household Income (2000 Dollar)</th>
<th>% in Poverty Status</th>
<th>% Unemployed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old City Establishment</td>
<td>58.7</td>
<td>14.1</td>
<td>$84,076</td>
<td>3.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Middle Class Suburbs</td>
<td>46.1</td>
<td>11.8</td>
<td>$53,627</td>
<td>7.6</td>
<td>4.2</td>
</tr>
<tr>
<td>Family Suburban Homeowners</td>
<td>30.3</td>
<td>7.1</td>
<td>$60,497</td>
<td>5.8</td>
<td>5.0</td>
</tr>
<tr>
<td>Emerging Middle Class/Asian Influx Suburbs</td>
<td>36.0</td>
<td>11.5</td>
<td>$50,044</td>
<td>10.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Young, Single, Educated and Mobile Renters</td>
<td>59.7</td>
<td>16.3</td>
<td>$43,940</td>
<td>15.9</td>
<td>5.1</td>
</tr>
<tr>
<td>White Working Class Suburbs</td>
<td>18.3</td>
<td>5.5</td>
<td>$49,466</td>
<td>8.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Cluster</td>
<td>% College Graduates</td>
<td>% Professional/Managerial Occupations</td>
<td>Median Household Income (2000 Dollar)</td>
<td>% in Poverty Status</td>
<td>% Unemployed</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------</td>
<td>--------------------------------------</td>
<td>--------------------------------------</td>
<td>---------------------</td>
<td>--------------</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Struggling Working Class Suburbs</td>
<td>14.9</td>
<td>6.6</td>
<td>$32,942</td>
<td>19.7</td>
<td>10.7</td>
</tr>
<tr>
<td>Low-Income Non-Traditional Household</td>
<td>17.6</td>
<td>8.0</td>
<td>$32,550</td>
<td>22.8</td>
<td>10.3</td>
</tr>
<tr>
<td>Disadvantaged Racial/Ethnic Enclave</td>
<td>17.5</td>
<td>8.0</td>
<td>$32,530</td>
<td>26.3</td>
<td>11.1</td>
</tr>
<tr>
<td><strong>Regional Mean</strong></td>
<td><strong>31.2</strong></td>
<td><strong>8.7</strong></td>
<td><strong>$53,534</strong></td>
<td><strong>9.9</strong></td>
<td><strong>6.2</strong></td>
</tr>
</tbody>
</table>

Table C-4 provides an overview of the housing characteristics.

**Table C-4: Housing Characteristics in Central Puget Sound Neighborhood Clusters**

<table>
<thead>
<tr>
<th>Cluster</th>
<th>% 2+ Person Non-Family Households</th>
<th>% Single Parent Headed Households</th>
<th>% in Overcrowded Housing</th>
<th>Median Gross Rent (2000 Dollars)</th>
<th>Median Housing Value (2000 Dollars)</th>
<th>% Owner-Occupied Housing Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Old City Establishment</td>
<td>8.2</td>
<td>5.6</td>
<td>1.1</td>
<td>$1,141</td>
<td>$385,567</td>
<td>66.3</td>
</tr>
<tr>
<td>Middle Class Suburbs</td>
<td>18.7</td>
<td>8.0</td>
<td>1.8</td>
<td>$833</td>
<td>$259,388</td>
<td>52.5</td>
</tr>
<tr>
<td>Family Suburban Homeowners</td>
<td>7.8</td>
<td>8.6</td>
<td>2.5</td>
<td>$913</td>
<td>$206,797</td>
<td>64.8</td>
</tr>
<tr>
<td>Emerging Middle Class/Asian Influx Suburbs</td>
<td>12.7</td>
<td>11.3</td>
<td>4.9</td>
<td>$845</td>
<td>$220,206</td>
<td>51.4</td>
</tr>
</tbody>
</table>

Appendix C: 8
<table>
<thead>
<tr>
<th>Cluster</th>
<th>% 2+ Person Non-Family Households</th>
<th>% Single Parent Headed Households</th>
<th>% in Overcrowded Housing</th>
<th>Median Gross Rent (2000 Dollars)</th>
<th>Median Housing Value (2000 Dollars)</th>
<th>% Owner-Occupied Housing Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young, Single, Educated and Mobile Renters</td>
<td>31.8</td>
<td>8.4</td>
<td>2.7</td>
<td>$806</td>
<td>$285,942</td>
<td>36.5</td>
</tr>
<tr>
<td>White Working Class Suburbs</td>
<td>8.0</td>
<td>11.3</td>
<td>2.9</td>
<td>$769</td>
<td>$160,968</td>
<td>62.1</td>
</tr>
<tr>
<td>Struggling Working Class Suburbs</td>
<td>12.4</td>
<td>19.8</td>
<td>5.6</td>
<td>$643</td>
<td>$128,623</td>
<td>42.8</td>
</tr>
<tr>
<td>Low-Income Non-Traditional Household</td>
<td>11.0</td>
<td>20.8</td>
<td>9.4</td>
<td>$657</td>
<td>$152,705</td>
<td>40.1</td>
</tr>
<tr>
<td>Disadvantaged Racial/Ethnic Enclave</td>
<td>9.6</td>
<td>18.2</td>
<td>14.7</td>
<td>$576</td>
<td>$154,756</td>
<td>45.3</td>
</tr>
<tr>
<td>Regional Mean</td>
<td>10.8</td>
<td>11.1</td>
<td>3.7</td>
<td>$841</td>
<td>$214,064</td>
<td>56.8</td>
</tr>
</tbody>
</table>

These characteristics informed the creation of the typology descriptions used in this study.
<table>
<thead>
<tr>
<th>Cluster</th>
<th>% 2+ Person Non-Family Households</th>
<th>% Single Parent Headed Households</th>
<th>% in Overcrowded Housing</th>
<th>Median Gross Rent (2000 Dollars)</th>
<th>Median Housing Value (2000 Dollars)</th>
<th>% Owner-Occupied Housing Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young, Single, Educated and Mobile Renters</td>
<td>31.8</td>
<td>8.4</td>
<td>2.7</td>
<td>$806</td>
<td>$285,942</td>
<td>36.5</td>
</tr>
<tr>
<td>White Working Class Suburbs</td>
<td>8.0</td>
<td>11.3</td>
<td>2.9</td>
<td>$769</td>
<td>$160,968</td>
<td>62.1</td>
</tr>
<tr>
<td>Struggling Working Class Suburbs</td>
<td>12.4</td>
<td>19.8</td>
<td>5.6</td>
<td>$643</td>
<td>$128,623</td>
<td>42.8</td>
</tr>
<tr>
<td>Low-Income Non-Traditional Household</td>
<td>11.0</td>
<td>20.8</td>
<td>9.4</td>
<td>$657</td>
<td>$152,705</td>
<td>40.1</td>
</tr>
<tr>
<td>Disadvantaged Racial/Ethnic Enclave</td>
<td>9.6</td>
<td>18.2</td>
<td>14.7</td>
<td>$576</td>
<td>$154,756</td>
<td>45.3</td>
</tr>
<tr>
<td><strong>Regional Mean</strong></td>
<td><strong>10.8</strong></td>
<td><strong>11.1</strong></td>
<td><strong>3.7</strong></td>
<td><strong>$841</strong></td>
<td><strong>$214,064</strong></td>
<td><strong>56.8</strong></td>
</tr>
</tbody>
</table>

These characteristics informed the creation of the typology descriptions used in this study.
Appendix D: Cumulative Assessment Detailed Results

The cumulative assessment of air quality hazards is a composite of a number of separate analyses. This Appendix contains detailed results for the individual air quality hazards that comprise the cumulative air quality riskscape, including: large-scale point source emissions, ambient air quality toxics, and small-scale point source emissions.

Large-Scale Facility-Based Hazards

The following analyzes large-scale facility based hazards in three parts: first, a breakdown of large-scale facilities reporting releases under the Toxic Release Inventory (TRI); second, analysis of the exposure risks from these facilities within the region; and third, a cluster analysis to identify areas of high toxic concentration of exposure risk.

Facility Releases

In 2014, 108 facilities in the Central Puget Sound region reported their emissions to the TRI, a decline of over 40 percent of the number TRI facilities reporting in 1990. While release amounts and toxicity of the releases declined from 1990 levels, associated with the de-industrialization of the region, the remaining risk begins to aggregate in the Duwamish Valley and Tukwila area located in South Seattle. Figure D-1 depicts the location of TRI facilities reporting in the region in 2014. Four of the top 10 facilities located in this area, comprising over 80 percent of the region's relative risk, now concentrate in South Seattle.
Figure D-1 TRI facilities in the Central Puget Sound region, 2014
Analysis of the reporting also indicates that many of the industries were established after 1990. In 2014, 38 new TRI facilities reported emissions; these facilities were not present in prior reporting years (2000 or 1990), as depicted by triangles (upright) in Figure D-1. Several new facilities were sited in areas newly designated for Industrial development in the study period. In addition, several facilities in areas that were re-designated from Industrial use are no longer reporting under the TRI program in 2014, indicating that these facilities have closed or relocated. In addition, of the 24 facilities that were located in areas designated as Regional Growth Centers, all but three are no longer reporting under the TRI program in 2014, indicating that these facilities have closed or relocated.

**Exposure Risks**

The distribution of industrial air pollution exposure was then evaluated at the more granular level provided by the RSEI-GM dataset in order to focus on the distribution of exposure, rather than spatial coincidence with large-scale facilities. Figure D-2 depicts the grid cell toxic concentration results for the 5-year period from 2010 to 2014 – the grid cells are classified into standard deviation based upon the total toxic concentration from all facilities that are modeled to impact the individual grid cell, averaged over the 5-year period. Dark brown areas depict grid cells with the highest relative toxic concentration levels, while light yellow depicts grid cells with the lowest relative toxic concentration levels. These results depict a concentration of exposure in South Seattle and Tukwila, as well as portions of Bainbridge Island and areas near Bremerton.
Figure D-2: Industrial Air Toxic Concentration by RSEI Grid Cell, 2010-2014
Clusters of High Exposure Risk

The results from the "global" Moran's I, which measures the broad regional tendency for values to cluster more closely tougher in space with similar values than would be expected if the data were drawn from a random distribution, found that pattern of toxic concentration values in 2014 was not due to chance. The Moran's I was greater than 0, indicating that the pattern is clustered.

Figure D-3 depicts the local Moran typology for the RSEI-GM toxic concentration values for 2010-2014. Toxic concentration in most census tracts does not exhibit statistically significant patterning. However, a total of 87 tracts comprise a cluster of census tracts containing high toxic concentration values (termed ‘High-High’ cluster to represent that two neighboring census tracts both have high toxic concentration values). These census tracts are agglomerated in the Seattle and Tukwila area and a small area in Bremerton. Toxic concentration values in these census tracts comprise approximately 42 percent of the regional total, and the mean toxic concentration value of the High-High cluster is 5.5 times higher than the mean for tracts not contained in the cluster.
Figure D-3: Moran typology of toxic concentration in Central Puget Sound region, 2010-2014
**Ambient Air Toxics**

The following analyzes ambient air toxics in three parts: first, a review of the different sources that contribute to ambient air pollution; second, analysis of the exposure risks from these sources within the region; and third, a cluster analysis to identify areas of high exposure risk.

**Ambient Air Quality Sources**

Ambient air quality is addressed in two parts: sources that contribute to cancer risk, and sources that contribute to respiratory risk and other non-cancer health concerns. The composition of the emissions sources contributing to cancer risk is depicted in Figure D-4. Secondary formation (when occurs when chemicals are transformed in the air into other chemicals) and on-road mobile sources are the largest contributors to cancer risks in the region, accounting for 58 percent of the risk. Industrial emissions, both point source and non-point source, are almost negligible in their contribution to overall cancer risks, emphasizing the importance of evaluating exposure to ambient air pollutants (Morello-Frosch *et al.* 2011).
The composition of emission sources contributing to non-cancer risks is slightly different than those contributing to cancer risk, with on-road mobile sources contributing the most, following by residential wood burning (Figure D-5). Industrial sources comprise a larger proportion of emissions sources contributing to non-cancer risks (approximately 10 percent).
Exposure Risks

This section turns to consider the potential exposure risks from non-point and mobile emissions using modeled information from the National Scale Air Toxics Assessment (NATA). Figure D-6 shows the relative cancer risks in the Central Puget Sound region, based on the 2011 NEI. The census tracts in the region are classified by standard deviation based upon the point and non-point sources that are modeled to impact an individual census tract. Dark brown areas depict grid cells with the highest relative cancer risk levels, while light yellow depicts grid cells...
with the lowest relative cancer risk levels. Cancer risk in this context is defined as the probability of contracting cancer over the course of a lifetime, assuming continuous exposure over a period of 70 years. Census tracts with the highest relative cancer risk are located in areas that contain dense development and busy transportation corridors and hubs, including the Seattle core area, the Tukwila and Kent area, the Everett corridor along I-5, and portions of Tacoma and Bellevue along I-405.
Figure D-6: Estimated cancer risk from 2011 NATA
Figure D-7 correspondingly depicts the relative non-cancer risks, specifically for the respiratory endpoint. Non-cancer risk in this context is defined as the risk associated with effects other than cancer, based on an estimate of an inhalation exposure that is likely to be without appreciable risks of deleterious effects during a lifetime. The census tracts in the region are classified by standard deviation based upon the point and non-point sources that are modeled to impact an individual census tract. Dark brown areas depict census tracts with the highest relative non-cancer risk levels, while light yellow depicts grid cells with the lowest relative non-cancer risk levels. The non-cancer risk has a similar spatial pattern as the cancer risks depicted above, but with an additional area of high risk located in the SeaTac area, near the International airport. Census tracts with the highest relative risk are located in areas that contain dense development and busy transportation corridors and hubs, including the Seattle core area, the Tukwila and Kent area, the Everett corridor along I-5, and portions of Tacoma and Bellevue along I-405.
Figure D-7: Estimated non-cancer risk from 2011 NATA
Clusters of High Exposure Risk

Similar to the results from Large-scale facilities, the "global" Moran I found that the pattern for cancer and non-cancer risk values was clustered. The spatial pattern of this clustering is depicted in Figure D-8 and Figure D-9, respectively. The area with high risk values is much larger for the ambient air risk values than the large-scale industrial facilities (termed ‘High-High’ cluster to represent that two neighboring census tracts both have high toxic risk scores). This is likely due to traffic congestion in the I-5 corridor from Seattle to Kent and in the I-405 corridor near Bellevue. Both types of cluster tracts (cancer and non-cancer) have greater than 1.5 times the within-tract concentration of air toxic lifetime risk than their counterpart non-cluster tracts. Unlike the point source facility information, the NATA results also identify areas of Low-Low Clusters, where contiguous tracts of relatively low risk values are present. These areas are largely located on the periphery of the region, away from traffic congestion and concentrated industrial development.
Figure D-8: Moran typology of lifetime cancer risk in Central Puget Sound region, 2011
Small-Source Air Pollution Facility Concentration

The following analyzes small-source air pollution in three parts: first, a review of the different sources; second, analysis of areas with a concentration of small-sources; and third, a cluster analysis to identify areas of high small facility concentration.

Small-Scale Sources

Small-scale facilities are often overlooked in traditional environmental inequality analysis, but contribute substantially to exposure risks (Maantay 2002; Sadd et al. 2014). In order to fill this gap, this study includes analysis of small-scale facilities. Figure D-10 depicts the spatial location of the over 1,200 facilities located across the region. Approximately 46 percent of these facilities are located in Industrial zoned areas, with others dispersed in other areas in the region. The types and number of the most prevalent business establishments included in this inventory is depicted in Figure D-11. Automotive body, paint and repair facilities are the most frequent type of facility, followed by coffee and tea manufacturing facilities.
Figure D-10: Spatial distribution of small-scale emissions sources in Central Puget Sound region
**Exposure Risks**

Figure D-11 depicts the type and frequency of small-scale emissions sources. Note: An additional 131 facilities, which have less than 10 business establishments in a specific category, are not included in this chart.

Approximately 49 percent of census tracts do not include small-source facilities, identified by the hatched markings. The density of facilities is dispersed in the region, but is generally higher along major transportation routes, including the I-5, I-405 and Highway 167 corridors.
Figure D-12: Area-Weighted Small-Scale Industrial Facility Density by census tract, 2016
Clusters of High Exposure Risk

Consistent with the large-scale facilities or the ambient air toxic risk values, the "global" Moran's I identified a spatially clustered pattern, indicating that the pattern of small-scale facility concentration does not appear to be random. When a Local Moran I analysis was completed, several contiguous census tracts that contained a high-density of small scale pollution sources was identified as a High-High cluster, shown in Figure D-13. The cluster is located in Seattle and Tukwila, including along Lake Union, in Downtown Seattle, and extending southward into the Duwamish Valley. Two smaller clusters are located east of Woodinville and southwest of Everett.
Figure D-13: Moran typology of small-source pollution facility concentration in Central Puget Sound region, 2011
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Morello-Frosch, R., Manuel Pastor, and James Sadd. 2001. “Environmental Justice and Southern California’s ‘riskscape’: The Distribution of Air Toxics Exposures and Health Risks among Diverse Communities.” Urban Affairs Review 36: 551–78.

Morello-Frosch, Rachel, and Bill M. Jesdale. 2006. “Separate and Unequal: Residential Segregation and Estimated Cancer Risks Associated with Ambient Air Toxics in U.S. Metropolitan Areas.” Environmental Health Perspectives 114 (3): 386–93.


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