Segregation as a multi-scalar phenomenon and its implications for neighborhood-scale research: the case of South Seattle 1990-2010

Abstract

Neighborhoods and neighborhood change are often at least implicitly understood in relation to processes taking place at scales both smaller than and larger than the neighborhood itself. Until recently our capacity to represent these multi-scalar processes with quantitative measures has been limited. Recent work on "segregation profiles" by Reardon and collaborators (Reardon et al., 2008, 2009) expands our capacity to explore the relationship between population measures and scale. With the methodological tools now available, we need a conceptual shift in how we view population measures in order to bring our theories and measures of neighborhoods into alignment. I argue that segregation can be beneficially viewed as *multi-scalar*; not a value calculable at some 'correct' scale, but a continuous function with respect to scale. This shift requires new ways of thinking about and analyzing segregation with respect to scale that engage with the complexity of the multi-scalar measure. Using block level data for eight neighborhoods in Seattle, Washington I explore the implications of a multi-scalar segregation measure for understanding neighborhoods and neighborhood change from 1990 to 2010.

Keywords: segregation, scale, Seattle

Introduction

In North Beacon Hill, a neighborhood that begins just a few miles south of Seattle's downtown, there is a large apartment building where every single resident is ethnic Chinese. Just a few doors down another apartment building houses families who, one suspects, almost all identify as Hispanic. A few blocks away there are streets lined with newly renovated single-family residences affordable only to professional households that are predominantly White. Taken as a whole North Beacon Hill is incredibly diverse, yet each of these groups may go days without encountering someone of a different race or ethnicity in or around their place of residence. In studying places like North Beacon Hill it is important to recognize that the overall diverse milieu of the neighborhood is, in fact, composed of several very different groups spatially clustered within its boundaries. What appears diverse at one scale is quite segregated at another.

If we consider North Beacon Hill within its broader context—South Seattle, Seattle, or even the Puget Sound region—we can see how the diversity of the neighborhood is also functionally related to both its immediate surroundings and its relative position within broader regional residential settlement patterns. North Beacon Hill was the place where Japanese and later Chinese families moved when they had saved enough money to leave the International District just to the North. Its proximity to employment in the downtown core and the presence of the El Centro de la Raza community center has made it a desirable location for Seattle's relatively small Hispanic population, otherwise dispersed outside of the City of Seattle. More recently, younger White households have purchased single-family residences in the area as neighborhoods to the North saw sharp increases in home prices. A significant but declining number of Black households are scattered throughout the neighborhood; legacy of the connecting role that the area played between the historically Black Central District to the North and the concentrations of Black households in the Rainier Beach and Othello neighborhoods to the South. The diversity of North Beacon Hill, both today and in the past, is a function of multiple push and pull factors each relating North Beacon Hill to other neighborhoods in the region and each exerting a strong pull or push on a specific sub group of today's residents. How North Beacon Hill is defined as a neighborhood and how residence in the neighborhood impacts the people who live there cannot be understood without an understanding of how other parts of the region are changing as well.

Conceptually, the narrative above is quite familiar to geographers; outcomes for neighborhoods (or places more generally) are a function of processes that manifest at a wide range of scales from the individual to the global. It is arguable that geographers' concern about the interrelationship of processes at multiple scales represents one of the discipline's primary contributions to social science across a range of topical areas (Latham, 2002; Marston, 2000; D. Massey, 2005; Pred, 1984). This literature makes it quite clear that it is the complexity of these processes and their interactions that are at the heart of a geographical understanding of place. In fact, one early survey of neighborhood definitions concluded that the complexity of the definitions with respect to scale was a source of strength as it avoided oversimplification of a "genuinely complex phenomenon" (Meegan & Mitchell, 2001, p. 2172 referencing the work of Davies and Herbert 1993)

There is an extensive body of qualitative/ethnographic literature that addresses the complexity of processes that come to shape neighborhoods such as North Beacon Hill. In fact it may be impossible to identify a case study of an urban neighborhood in geography or related fields that does not work to sort out the complexity of processes at multiple scales. For example, Woldoff's analysis of a neighborhood in Philadelphia looks at individual demographic characteristics such as age, social relationships among households, and city-level patterns of investment and disinvestment in neighborhoods (Woldoff, 2011). Auyero and Swistun intermix individual survival strategies, community efforts at joint action, and government and international corporate action in their study of Villa Inflamable, Argentina (Auyero & Swistun, 2009). In his ethnography of the street culture of East Harlem Philippe Bourgois weaves individual relationships, neighborhood characteristics like immigration history, and broader structural economic features to explain how and why people become involved in drug culture and why they remain involved in a way that makes it clear that both the neighborhood and the individuals who reside in it are jointly influenced by these elements at different scales (Bourgois, 2003). A clear message from these works, and innumerable others in this same tradition, is that to understand a neighborhood one must understand how processes operating at multiple scales come together both in terms of impacts on individuals and in terms of defining a context that is identifiable as a neighborhood.

The quantitative representation of populations and neighborhoods in terms of processes at multiple scales has not kept pace with our theorization. There is wide acknowledgement that population measures vary with scale, but little evidence of measures that describe places in terms of this variation. Duncan et al. (1961) cautioned about the effect of scale on measures of segregation as early as 1961 while the Modifiable Areal Unit Problem (MAUP) addressed by Openshaw and others (Openshaw & Taylor, 1979; Openshaw, 1977) brought the issue of scale and aggregate measurement to a broad audience. These authors and many others were certainly sensitive to the fact that population measures vary with scale, but the issue is regularly addressed as a problem to be solved (through better aggregating units) rather than as a source of information about the processes that affect our units of analysis (O'Sullivan & Wong, 2007; Osth, Malmberg, & Andersson, 2014; Wong, 2010).

Moving away from concerns about the 'correct' scale for measuring population characteristics the 'neighborhood effects' literature is one of several research areas that is increasingly sensitive to the variety of scales at which processes may be relevant to individual experience (Clark, 2005; Ellen & Turner, 1997; Goering, 2013; Leventhal & Brooks-Gunn, 2003; van Ham, Manley, Bailey, & Simpson, 2012; Wilson, 1987). This literature often employs multi-level models to explain outcomes for neighborhoods and populations in terms of processes relevant to individuals, households, neighborhoods, and larger regions such as school districts, cities, or labor markets (Sampson, Morenoff, & Gannon-Rowley, 2002; Sampson, 1997; van Ham et al., 2012). Generically, these efforts tend to describe the effect of a neighborhood as conditioned on individual, neighborhood, and regional characteristics with an emphasis on singling out the impacts for individuals explicitly linked to residence in a given neighborhood. While these efforts acknowledge the importance of multiple scales in shaping outcomes, they tend to conceptualize scale as hierarchical and clearly bounded in ways that many geographers find problematic (Marston, 2000). What is missing from these multi-level approaches is a sense of how scale itself is implicated in the complex outcomes experienced by residents in a neighborhood.

The difference between a multi-level approach to scale as described above and one that is multi-scalar can be usefully illustrated with an example. For North Beacon Hill we might choose to measure segregation at the scale of the census block and again based on the administrative boundary for Beacon Hill assigned by the City of Seattle (a multi-level approach). Depending on where the census block was within the neighborhood we would likely see some degree of segregation at the smaller scale and less segregation at the neighborhood scale. This two-scale measurement is clearly an improvement on a single measurement particularly one based on an arbitrarily drawn spatial unit like the census tract (Grengs, 2013). However, the proposed measures just described imply a theoretical claim about what scales matter for segregation and they ignore the role of the broader context in which the neighborhood is situated. If, instead of just two measurements we were to take many measurements extending out from a point across a wide range of scales then we find ourselves with a “segregation profile” (Reardon et al., 2008) or an “egocentric signature” (Spielman & Logan, 2013), a representation of the relationship between population and scale that conveys, not only the magnitude of segregation at a particular point, but describes how the measure changes as our scale of observation increases. This more complex representation lets us ask questions about what scales are relevant rather than assuming we know *a priori.* Even more central to the argument for a multi-scalar conception of population measures, this representation also gives us: the opportunity to examine how segregation changes with scale, a chance to examine the spatial extent of a segregated context, and information about the rate of change as local conditions (segregation or diversity) blend with the broader milieu. Our understanding of neighborhoods is similarly enhanced as we can group together small areas with similar segregation profiles rather than trying to bind places together based purely on homogeneity or an arbitrary administrative border (Spielman & Logan, 2013).

Recently, scholars have begun to explore population characteristics represented as a continuous measure with respect to distance, population, or income; examining not just differences in population measures but differences in how population measures vary with scale. The “segregation profile” developed by Reardon and colleagues is the starting point for much of this work (Reardon et al., 2008, 2009). Lee et al. examine segregation profiles for U.S. metro areas and note differences in the spatial scale at which segregation is most relevant in different metros while offering comparisons related to the differing slopes of the segregation profile among a set of four metro areas (Lee et al., 2008, p. 773). Osth et al. pursue a similar set of conclusions using a different mechanism for generating segregation profiles, identifying the population scales (rather than distance scales) that ‘matter’ for segregation in Swedish cities (Osth et al., 2014). Spielman and Logan take individual-level historical census data and use egocentric population profiles to group like areas into neighborhoods (Spielman & Logan, 2013). Several authors have combined spatial segregation measures with income to look at segregation profiles across income groups as a means of comparing the structure of socioeconomic segregation across metropolitan areas and across decades (Monkkonen & Zhang, 2014; Reardon & Bischoff, 2011a, 2011b).

Although the above work represents a significant advance in our capacity to describe variation in population measures with scale, the full potential of these measures cannot be reached until the measures themselves are reimagined as inherently multi-scalar. The studies above all report population measures at a range of scales. They move away from efforts to seek a “correct” scale of analysis, but do not fully embrace the task of describing and analyzing profiles as a meaningful whole. Spielman and Logan perhaps come closest to treating their measures as multi-scalar. They begin with “egocentric signatures” representing the context of each individual and then use model-based clustering to group these individuals into overlapping neighborhoods based on the similarity of the signatures (Spielman & Logan, 2013). While their work does make use of the full range of data for egocentric neighborhoods, they acknowledge that the model-based clustering technique is aspatial and atheoretical in its grouping of different signatures (Spielman & Logan, 2013, p. 11). Perhaps more importantly from the perspective of this analysis, the clustering of egocentric neighborhoods does not explicitly engage with the *form* of the signatures, thus favoring data at multiple scales over a multi-scalar interpretation of the data.

Methodologically and theoretically, a multi-scalar conceptualization of population measures needs to engage in terms of the key characteristics of the function relating population and scale: intercept, slope, inflection points, etc… Advocating for a conceptualization of population measures as multi-scalar is the theoretical contribution of this paper. Establishing a framework for analyzing and visualizing population measures as multi-scalar is the methodological contribution.

Once we begin to imagine places as being composed of multi-scalar relationships (ethnic/racial diversity is the example used here, but the same logic would apply to any number of other factors from housing cost to environmental conditions), three key questions arise:

1. How does the relationship between segregation and scale vary? What functional forms best describe the relationship between segregation and scale?
2. From both a theoretical and empirical perspective what are the key elements of the functional form that can help us understand both outcomes for populations and the similarities and differences among places? How can these key elements help us delineate areas of effect or borders between meaningful spatial units?
3. Where and how does the functional form change or stay the same as we compare places in space and change over time? What patterns are meaningful for understanding how and why specific places are subject to change?

Definitive answers to these questions go beyond the scope of a single paper, but the intent here is to lay out a starting point for a research agenda that includes both a treatment of how we might capture the most salient elements of multi-scalar segregation for small geographic areas and how we might group these areas together to identify regions of similarity. In pursuing this framework I hope to demonstrate that a multi-scalar representation of population measures brings our quantification and representation of th e processes that form neighborhoods and impact residents into line with our existing theories of these places and their relationships to the outcomes of the people that inhabit them.

In this article I address questions (1) and (2) above as I further develop the idea of segregation as a multi-scalar phenomenon and identify key elements of the functional form that have resonance with our theories of how segregation is related to outcomes for individuals and may also be useful for research on neighborhoods. The four key elements of functional form that I identify are: *initial intensity, neighborhood size, decay, and limit.* I argue that these four parameters offer an important way to talk about the relationship between segregation and scale in multi-scalar terms.

In the analysis portion of this paper I empirically test the four key elements just described using block level data for eight neighborhoods in South Seattle. I employ a standard clustering algorithm on three decades of data for South Seattle and arrive at a typology of four distinct functional forms that represent unique combinations of these four key elements. The four functional form clusters I identify in South Seattle are: *flat, rising, standard, and steep* and I make an argument why these specific groupings of functional forms may be useful for describing places in general and South Seattle in particular.

Finally, in the second part of the analysis I take up the challenge posed in question (3) and generate maps showing the spatial distribution of the key elements of the functional form and of the clusters derived from these elements. I map the functional forms over three decades, from 1990 to 2010, to visualize how the segregation profiles change over time. Although the complexity of the relationship between scale and segregation resists easy categorization this exercise identifies spatial clusters of similar functional forms that may contribute to our understanding of the scale of certain neighborhoods. Examining the changes in these typology maps over time provides information on the dynamics of neighborhoods both in terms of how their functional forms change and how their borders grow or shrink.

This article continues in four parts. In the following section I present the trajectory of research that has led to the development of multi-scale population measures. This section also provides a technical background on the measure, Thiel's H, which I employ in the subsequent analysis. Next, I offer a justification for the choice of South Seattle as a case study that focuses on the unsolved puzzle of the area's stable, racial/ethnic diversity. The analysis section then returns to the research questions defined above. I examine the functional form of segregation with respect to scale and propose a mechanism for differentiating among places based on four key characteristics of the functional form (*initial intensity, neighborhood size, decay, and limit*). Using this classification scheme I identify four distinct functional forms that are most clearly visible in South Seattle (*flat, rising, standard,* and *steep*). I conclude the results section by mapping the occurrence of these four functional form groups across three decades. In the final section I consider some directions for future research employing this method and identify both its potential and limitations.

Segregation measures from Duncan and Duncan to the segregation profile

Concerns about residential segregation have produced a vast literature over the past sixty years with methodological advances and shifting demographic trends gradually increasing the sophistication of our understanding of both the form that segregation takes and the impacts it has on individuals and society. The key contribution of this article is principally a conceptual one; providing a framework for analyzing segregation as multi-scalar. Nevertheless, the technical capacity to represent segregation in this way draws extensively from recent contributions to our understanding of segregation. The litany of key milestones from Duncan and Duncan (1955) to Massey and Denton (1988) and beyond is well covered elsewhere (cf. Farrell, 2008) but three areas bear further discussion here: developments in multi-ethnic measures of segregation, inclusion of spatial information in segregation measures, and finally the consideration of segregation at multiple scales.

Measures of Multi-ethnic Segregation

A relatively recent development in work on residential segregation has been a move away from binary racial/ethnic comparisons into more nuanced multi-group comparisons (Reardon & Firebaugh, 2002). This is an important development because the U.S. population is becoming more diverse with significant growth in both Hispanic and Asian racial/ethnic groups. With increased diversity, binary comparisons become less and less useful as the 'base' comparison category (historically non-Hispanic White) is less meaningful and the focus of research is increasingly aimed at diversity rather than segregation (Freeman, 2009; Holloway, Wright, & Ellis, 2012; Maly, 2000, 2005; Wang, 2012).

The clear favorite for analyses of multigroup segregation is Entropy (E) often transformed for comparability across regions into Theil's H (H). While there is some small variation in the specific formulas for both E and H, Reardon and Firebaugh (2002) in their comprehensive review of multigroup segregation measures employ the form:

$$E = \sum_{m=1}^{M} \pi_m \, ln\left(\frac{1}{\pi_m}\right) \quad (1)$$

$$H = \frac{1}{E}\sum_{m=1}^{M} \pi_m \sum_{j=1}^{J} \frac{t_j}{T} r_{jm} \, ln \, r_{jm} \quad (2)$$

where m indexes the M racial/ethnic groups, j indexes the units of J observations (e.g. tracts), t_j denotes the count of individuals in unit j summing to T the population for the region as a whole. π_m denotes the proportion of the total population in group m, and $r_{jm} = \pi_{jm}/\pi_m$ the ratio describing the extent to which group m is disproportionately represented in unit j.

The popularity of H is based in large part on its decomposability; that is the capacity to identify the share of total segregation that is attributable to a specific group or a specific sub-unit within a larger region (Clause S Fischer, Stockmayer, Stiles, & Hout, 2004; Parisi, Lichter, & Taquino, 2011; Reardon & Firebaugh, 2002; Reardon et al., 2008). This is important for the purposes of this analysis because it allows us to report the specific level of segregation for each of our units of observation. H also has the advantage of offering a value that sets up a continuum from segregated to diverse such that 1 equals complete segregation (entire population in sub unit is of one race/ethnicity), zero indicates that the population distribution is exactly equal to the population distribution in the region as a whole, and negative values indicate diversity greater than that found in the population as a whole. Maximum diversity (minimum H) is achieved when all population groups are represented in exactly equal proportion, the actual minimum value is a function of the number of population groups and the distribution of the population in the region as a whole.

Measures of Spatial Segregation

A second relevant development in the literature on residential segregation is the recognition that spatially proximate units are not completely independent of one another and should not be treated outside of their spatial context (Anselin, 1989; Openshaw & Taylor, 1979). Aspatial measures of segregation are subject to the Modifiable Areal Unit Problem (MAUP Openshaw, 1977)—that is, the results of analyses based on aggregate data will be subject to change if the boundaries of the aggregating units are changed. The utility of aspatial segregation measures thus depends on how meaningful the aggregating unit is. Beginning with Morrill (1991) a rapidly growing literature has proposed new and better mechanisms for incorporating proximate observations into measures of segregation as a means of improving the aggregating unit and consequently the measure of segregation (O'Sullivan & Wong, 2007; Reardon & O'Sullivan, 2004; Wong, 1993, 2003, 2005, 2010; see Wong, Reibel, & Dawkins, 2007 for a recent survey). The measure of spatial segregation that underlies the multi-scale segregation measure employed here was first proposed by Reardon and O'Sullivan (2004). The measure relies on a weighting function to establish the "local environment." Within the local environment of a point p we can calculate the population proportion of a racial/ethnic group m ($\tilde{\pi}_{pm}$) with observations nearer to p

weighted more heavily and points outside of the local environment all weighted to zero (Reardon & O'Sullivan, 2004, p. 129). Given $\tilde{\pi}_{pm}$ the formula for Entropy from Equation 1 can be rewritten with some changes to reflect the fact that the measure is calculated using population density rather than population counts and to facilitate decomposition across *p*:

$$\tilde{E}_p = -\sum_{m=1}^{M} (\tilde{\pi}_{pm})\, log_M(\tilde{\pi}_{pm}) \quad (3)$$

the equivalent spatial version of H, denoted $\tilde{H}$ can be written as:

$$\tilde{H} = 1 - \frac{1}{TE}\int_{p \in R} \tau_p\, \tilde{E}_p dp \quad (4)$$

where T and E are the total population and entropy respectively in the region R, τ_p is the population density at p, and the integral (again following Reardon and O'Sullivan's notation) indicates the summation across all locations within R. The decomposition of $\tilde{H}$ for each point p can then be written as:

$$\tilde{H}_p = 1 - \frac{\tau_p \tilde{E}_p}{E} \quad (5)$$

$\tilde{H}_p$ tells us how the level of segregation at a given location and a given local environment compares to the average level of segregation in the region as a whole. By changing the size of the local environment used to calculate $\tilde{\pi}_{pm}$ and thus $\tilde{E}_p$ we can generate values of $\tilde{H}_p$ indexed by the radius d of the local environment$\tilde{H}_{pd}$.

In thinking about how $\widetilde{H}_{pd}$ characterizes the local environment we need to consider what gets included and what does not. Reardon and O'Sullivan (2004) note that the choice of a specific weighting function is not tremendously important (I follow their choice and employ a bi-weight kernel with a power of 2), but understanding the rate of decay for this weighting function is essential. Considering the applicability of the measure more broadly, the dependence on a circular definition of the local environment suggests some problems for a region with a complex physical geography like Seattle. Better measures of the local environment might reflect activity space, travel time, or travel frequency, but the complexity entailed in pursuing these kinds of representations is prohibitive (Ellis, Wright, & Parks, 2004; Matthews, 2008).

Multi-scale segregation

Intertwined with the recognition that segregation measures should take note of the spatial context of individual observations, researchers have also begun to examine how different assumptions about the spatial extent of observations changes findings related to the degree of segregation. Fischer et al. (2004) and Parisi, Lichter, and Taquino (2011) decompose segregation to compare the contribution of different geographic scales. Both sets of authors find, among other conclusions, that Black segregation is based more on concentration within certain cities and less on neighborhood level segregation. Their work represents a crucial step in identifying the scales at which segregation matters.

Building on the spatial segregation measure previously described, Reardon and colleagues have proposed the "segregation profile" (Reardon et al., 2008) that expresses segregation as a function of scale. A segregation profile is simply a line connecting all the values of $\tilde{H}_{pd}$ for a single value of p given a vector of relevant distance values for d. By choosing values of d that extend from a fairly small distance out to something close to the entire region (typically a metropolitan region in the work published to date), the complete range of values for $\tilde{H}_{pd}$ can be examined at once.

In a series of articles Reardon and colleagues have compared the segregation profiles for various metropolitan areas ($\tilde{H}_d$ the aggregate measure for all values of p within a metropolitan area) and identified differences in the overall patterns of segregation (Lee et al. 2008; Reardon et al. 2008, 2009). In these papers they note that different racial/ethnic groups have different segregation profiles and that those profiles also differ across metropolitan areas. Similar work has explored these outcomes with segregation expressed as a function of population instead of scale (Östh, Clark, & Malmberg, 2014; Osth et al., 2014) and by exploring relationships decomposed for income instead of race (Monkkonen & Zhang, 2014; Reardon & Bischoff, 2011a). Perhaps closest to the work presented here, Spielman and Logan (2013) employed individual level data from the 1880 decennial census and generated profiles using a different set of metrics based on population counts as a function of scale. Key to its relationship with this article, Spielman and Logan (2013) used a clustering algorithm on these population profiles to identify patterns of similarity across space as a mechanism for defining neighborhoods.

While each of these contributions has added significantly to our understanding of segregation, their consideration of how segregation varies with scale has been limited to model based findings of similarity (Spielman & Logan, 2013) and general statements about differences in slope (Lee et al., 2008). Missing from this literature is any effort at describing the ways that segregation and diversity can be present at different scales for the same place or a consideration of the different paths that places can follow to go from local measures to the regional average as the scale of analysis goes from small to regional.

Segregation as a multi-scalar population measure: Identifying the theoretically relevant components of the relationship between segregation and scale

A key methodological contribution of this article is to characterize the form of the segregation profile for very small geographic areas as a means of distinguishing among different forms of segregated or diverse neighborhoods. Mathematically, this article reports the value of $\widetilde{H}_{pd}$, generating segregation profiles for each point p within region R instead of reporting the profile for $\widetilde{H}_d$ in a region. This has already been done on a comparative basis for two values of d (500m, and 4000m) by Reardon et al. (2008). The contribution of this article is to explore the functional form of these individual segregation profiles and to work through the implications of multi-scale segregation not in a comparative sense as Reardon et al. (2008) do, but with the goal of treating the phenomenon of segregation as simultaneously multi-scalar.

If we return to the example of North Beacon Hill with which this article commenced, the functional form of segregation with respect to scale examined for small geographic units has the capacity to signal which kinds of settlement patterns are remarkable in a place. Is there a uniformly Chinese apartment building across the street from the Hispanicoriented community center? We should see at least two spikes in segregation at very small scales with a sharp drop towards diversity at slightly larger scales. Is Beacon Hill a landing pad for Asian populations leaving the International District just to the north? We may be able to observe the spillover effect of the International District by identifying a segregated center with tapering levels of segregation extending outward into surrounding neighborhoods. Patterns like these are complex, but so are residential settlement patterns. Research on neighborhood change and segregation is at a turning point where the classic models of invasion and succession or of White flight and concentrated Black poverty are clearly still relevant but no longer sufficient. As researchers grapple with the complexity of this phenomenon it is appropriate to expand the complexity of our representations. A central argument of this article is that a significant portion of this complexity will be conditioned on spatial relationships at and across multiple scales.

Conceptualizing segregation as a phenomenon that is multi-scalar in the sense of being composed of processes operating simultaneously at multiple scales takes another step beyond existing work that acknowledges that segregation varies across scale. In advancing a theoretical frame for this conceptualization the work of Holloway, Wright, and Ellis (2012) is helpful. Although their argument is developed for a different purpose, the language employed by Holloway, Wright, and Ellis (2012), that segregation and diversity are "enfolded" rather than opposite ends of a particular spectrum, is conceptually quite useful (Holloway et al., 2012, p. 64). In this conception segregation and diversity create one another just as the segregated enclaves combine to create a diverse milieu in North Beacon Hill. Despite a growing literature on segregation at multiple scales, this is the only reference I am aware of that explicitly acknowledges that segregation outcomes at one scale are *dependent* on outcomes at another. The advantage of this multi-scalar conception is that we don't have to 'choose' a status (diverse or segregated) for a given neighborhood so much as represent the specific context in which segregation and diversity relate to one another.

Figure 1 offers a sketch of how a single location might be understood as segregated or diverse depending on the scale of measurement. At the left of the diagram a single grey individual is completely segregated (only one of the two possible kinds of individual in the population). We can imagine segregation in this context as a continuous variable being recalculated with every step as our grey individual walks down the street adding every individual she passes to a running tally (Spielman & Logan, 2013 use the same imagery of walking down a street to describe the calculation of their egocentric profiles). The first person she passes is green and the tally of segregation changes from perfectly segregated to perfectly diverse (one of each color in a population of two). Extending outward, as her walk continues past an apartment building that houses only grey individuals the measure returns to a relatively high level of segregation. This relatively high level continues as scale increases until the local environment grows enough to contain a building that predominantly houses green individuals. At the right edge of the diagram, presumably the border of our region *R*, we have a count of eleven grey individuals and nine green individuals resulting in a fairly diverse measure for the 'region' as a whole. If we change our example from a walk down the street to a circle of expanding radius and distance-weighted populations, we have exactly the process by which we generate a functional form for multi-scale segregation.

[Figure 1]

Figure 1 helps us visualize how small segregated places (the first apartment building our walker passed) can contribute to larger diverse places, but as we move forward with this concept towards developing a typology of multi-scalar relationships it is important to draw out the aspects of this functional form that are likely to be of interest. Representing the intensity of segregation (or diversity) at small scales will certainly be important in pinpointing the 'centers' of segregated or diverse places so we will want to pay careful attention to the *initial intensity* of our segregation profile; the value it takes at the smallest local environment in $\widetilde{H}_{pd}$. *Initial intensity* could be expected to capture the Chinese-only apartment building in North Beacon Hill with its highly localized, extreme segregation.

Another useful measure of the segregation profile may be the *neighborhood size*; how large can we make the local environment before the *initial intensity* starts to decline. We expect that segregation will be most intense at small scales given the predominance of same-race households. By definition, our measure of segregation $\widetilde{H}_{pd}$ will go to zero as d grows large enough to capture the entire region. *Neighborhood size* should capture the distance at which the intensity of the small scale measurements begins its decline towards the regional average. To the extent that a neighborhood is defined by a uniform level of segregation/diversity (as opposed to a definition based on a homogenous racial/ethnic grouping) this measure is likely to be valuable in defining the extent and borders of a neighborhood as well as telling us how far from the edge of a neighborhood a given location is. *Neighborhood size* will help to distinguish between the micro-enclaves discussed with respect to North Beacon Hill and the much larger concentration of the International District. Extending to other contexts one can imagine real utility in visualizing the degree to which a highly segregated place is centrally located or at the periphery of an area of homogenous population; *neighborhood size* should be able to pick up this distinction.

A third measure of theoretical interest is the rate of *decay*; once we reach the edge of the neighborhood as defined by *neighborhood size* how fast does the level of segregation change. *Decay* is an important metric because it will help us understand how strong or weak the borders of the neighborhood are likely to be. If we set out to understand how processes shaping residential location diffuse we might theorize different rates of diffusion in the presence of steep rates of *decay* vs. slower rates. Conceptually, some processes might be more rapid where borders are less clear (there is less of a barrier to diffusion), while other processes might be more rapid where borders are sharp (the difference across the border creates opportunities for expansion when profit motives are at work). In North Beacon Hill, the growing Asian population extends south along a North to South glacial moraine. This enclave grew through a process of diffusion based on increasing distance from the International District, and moving south there was little change in housing stock or level of connectivity to impede this process. To the West, however, a largely impassable slope ultimately blocked by Interstate 5 forms a hard boundary. We would expect *decay* to be gradual to the south of North Beacon Hill and sharp to the west. A note on terminology, *Decay* denotes a falling functional form, appropriate in most contexts since we typically expect places to exhibit homogeneity at small scales. Nevertheless, diversity at small scales is both possible and empirically observable in South Seattle. In the analysis that follows *decay* will also be used to describe the positive slope of the functional form when diverse neighborhoods return towards the regional average.

Finally, when the size of the local environment gets large enough to include the entire region, *R*, $\widetilde{H}_{pd}$ will go to zero by definition since the local environment and the region are then the same. If we limit our segregation profile to something less than *R*, however, then the *limit* of our profile, the value of $\widetilde{H}_{pd}$ for the largest local environment we measure will give us a broad sense of how a place *p* compares to other places in the region. As we theorize whether regions are moving towards diversity or segregation overall, it will be helpful to see how particular places fit into the larger whole.

Given the way the segregation profile is constructed we expect to see the most intense values of $\widetilde{H}_{pd}$ (either positive or negative) at small values of *d* with a trend towards the regional average as *d* increases. We can conceptualize a functional form mathematically using a standard exponential function with the four key components described above immediately derived from the shape parameters of that function:

$$\widetilde{H}_{pd} = \frac{m}{1 + e^{\left(\frac{b}{1000}\right) + \left(-c * \frac{d}{1000}\right)}} + a \quad (6)$$

where $\widetilde{H}_{pd}$ is the estimated value of $\widetilde{H}_{pd}$ given the shape parameters *a,b,c,* and *m* and a distance parameter *d.* Given this standard form for the exponential, our key components are:

$$\begin{bmatrix} I = a \\ NS = \frac{b}{c} \\ D = \lim_{x \to 0} \frac{\Delta \widetilde{H}_{pd}}{\Delta x} \; at \; d = NS \\ L = a + m \end{bmatrix} \quad (7)$$

where *I* is *intensity*, *NS* is *neighborhood size*, *D,* the slope of the functional form at its inflection point, is *decay*, and *L* is *limit.*

This mathematical form is represented graphically in Figure 2. The exponential function is meant as a starting point for thinking about what characteristics of the segregation profile might be interesting from the perspective of utilizing functional forms to analyze neighborhoods. It has the advantage of approximating many of the most common functional forms observed empirically in South Seattle, and its shape parameters easily translate into the concepts that are of theoretical interest for the analysis. There are an almost limitless number of possible functions that could serve as the basis for conceptualizing multi-scalar segregation and the variables of interest and the base function will need to be tailored to the specific region and questions under consideration. The schematic presented here is meant as an example only, although it will prove to be useful for representing neighborhoods and neighborhood change in South Seattle.

[Figure 2 about here]

As far as operationalizing these measures $\tilde{H}_{pd}$ can be obtained by fitting a curve (using a standard linear optimization tool) to the empirically generated values of $\tilde{H}_{pd}$ such that the squared error between $\tilde{H}_{pd}$ and $\tilde{H}_{pd}$ is minimized. The parameter values generated from $\tilde{H}_{pd}$ as described in Equation (7) usefully serve to characterize the complex shape of $\tilde{H}_{pd}$ in a smaller set of variables each with some theoretical rationale. Significantly, each of the four parameters derived in this way describes an important characteristic of the functional form of segregation over scale as opposed to a single measure of segregation at a particular scale. Having defined the measure we will use in our analysis and the key components of the functional form that may be relevant for interpreting that measur e as multi-scalar we next turn to the empirical example of South Seattle so that we can see these measures as they apply to real places.

Neighborhood Segregation and Diversity in South Seattle

This study focuses on a series of largely diverse neighborhoods in South Seattle, Washington (Figure 3). South Seattle offers a useful case study because it is highly diverse overall and also features an unusually large variety of different neighborhood configurations including majority White, majority Black, and majority Asian. South Seattle has been remarked upon as unusual for the stability of its diversity (Cashin, 2004, p. 52; Gordon, Locke, & Ulberg, 1998; Nyden, Maly, & Lukehart, 1997) and the basis for this stability is a key focus of a larger research project on the region of which this paper is a component.

[Figures 3]

The period of study, from 1990 to 2010, captures two decades in which the economy of the Seattle metropolitan region changed dramatically. Indeed, two of the iconic corporations associated with Seattle's rise to prominence, Starbucks and Amazon.com, are headquartered in or adjacent to the study area (although Amazon has subsequently moved its headquarters to the North of the downtown core). Despite the growth in the economy, a period of radically rising housing costs in the region, and extensive gentrification pressures in other parts of the city, South Seattle retained most of its socioeconomic diversity. If we can understand why and how South Seattle retained its racial/ethnic diversity during this time period we have the potential to advance our knowledge of when and why neighborhoods remain diverse.

Even as South Seattle is noted for the stability of its diverse neighborhoods, those same neighborhoods are presently undergoing significant change in response to major investments in housing and infrastructure, new immigrant and refugee communities, and a tightening housing market in other parts of the city. In many respects, the time period of this study captures a baseline for South Seattle in terms of its status as a stably diverse region. The new light rail line that runs from Downtown through South Seattle to the airport has begun a process of new private investment in multi-family housing units that has been completely absent from the area for decades. This private investment is coupled with the buildout of two major Hope VI housing projects. Some of this change is captured in the 2000 to 2010 time period, but what is visible from those two census years may be the tip of the iceberg as far as change is concerned. Careful examination of the multi-scale segregation measure may offer important clues as to why some places stay the same and others change.

Data

The research presented here follows a well-trod path in the literature on residential segregation employing block level data from the decennial census and an established method for calculating spatial segregation (Reardon and O'Sullivan 2004). Nevertheless, there are several areas where this article conveys methodological innovations that bear further discussion. This article supports current standards in reproducible research (Gentleman & Lang, 2007) and a version of the paper with all of the code and data to reproduce every element of the analysis using open source statistical software is available from the author on request.

This study is based on block level data from the U.S. decennial census for the years 1990, 2000, and 2010. The focus is on blocks that fall within the neighborhood boundaries of eight South Seattle neighborhoods (Figure 3). For each census year six panethnic categories were identified: non-Hispanic White, non-Hispanic Black, non-Hispanic Asian and Pacific Islander, non-Hispanic Native American, Hispanic, and Other. These categories were selected for consistency with other research on multi-group segregation and to maximize the comparability of categories across the three census years.

Edge effects are a major concern with spatial measures of population. To reduce the impact of edge effects, the actual census block coverage employed in generating the segregation measures included all census blocks whose centroid fell within twenty thousand feet of the neighborhood boundaries shown in Figure 3. Edge effects are probably still relevant to some degree as the largest spatial contexts for many observations include extensive zero population counts where the extent overlaps Elliott Bay to the West or Lake Washington to the East of the study area. Where the 20,000 foot buffer extended across Lake Washington to include Mercer Island, a wealthy enclave, or portions of the Eastside shoreline those centroids were clipped from the analysis as significant outliers both spatially and socioeconomically.

For consistency with previous work employing segregation profiles, the block-level population counts were converted to a population density surface and then interpolated to a matrix of approximately one-hundred foot by one-hundred foot (30.48 meters square) raster cells (see Reardon and O'Sullivan 2004 for a more detailed description of the smoothing and interpolation processes involved). These uniform cells are advantageous because they allow for homogeneity in how much data is included in each segregation calculation (both in space and over time) and their small size increases the variation in segregation measures. Conversely, the small size may artificially inflate the variation at particularly small scales. Robustness checks using larger cell sizes (300 by 300 foot and 800 by 800 foot cells) substantially reduced the variation in segregation and reduced the divisions across cells. Ideally, these measures would be undertaken with individual level data (cf Spielman and Logan 2013) but this is the finest level of variation permitted using current census data.

As described above in the section on spatial segregation, the spatial segregation profile developed by Reardon and colleagues (Reardon & O'Sullivan, 2004; Reardon et al.,

2009) uses $\widetilde{H}_{pd}$ as its measure of segregation. The segregation profiles represented here for individual values of p, thus represent the line connecting the segregation measure as defined for the same observation with increasingly large local environments. For the purposes of this article $\widetilde{H}_{pd}$ was calculated for twenty-five local environments at equal intervals between 100 feet and 11,000 feet. At its broadest scale, the local environment is large enough to cover the entire study area for cells near the center of the study area and about half of the study area for cells near one of the ends. For robustness, the analysis was also conducted with a maximum local environment of 20,000 feet (3.8 miles or 6.1 kilometers), but diagnostics suggested that most of what separated local environments was occurring within the first half of the local environment and the larger environment bringing in increasingly problematic outliers to the North and East of the study area.

The end result of the steps reported here is a series of twenty five raster layers each containing the spatial segregation measure for approximately thirty-six-thousand cells with each distinct raster layer representing $\widetilde{H}_{pd}$ based on a different local environment defined by *d.* The data is replicated for each of three Census years 1990, 2000, and 2010. In the following section I detail the results of a cluster analysis grouping these one-hundred and eight thousand segregation profiles (36,000 observations x 3 Census years) based on the four key measures *intensity, neighborhood size, decay,* and *limit* described above and then analyze the maps showing the spatial extent of different functional forms and their change over time.

Establishing a Typology of Functional Forms for South Seattle

Figure 4A displays a single raster layer conveying the spatial segregation measure $\widetilde{H}_{p600ft.}$, $\widetilde{H}_{pd}$ given a 600 foot local environment, an area of approximately 0.04 square miles or 0.10 square kilometers. This single raster can be understood as one of the twenty five 'slices' that together comprise the segregation profiles shown in Figure 4B. Figure 4B includes the segregation profiles for approximately 36,000 raster cells from the 1990 census colored based on their *initial intensity,* the smallest value of *d*, 100 feet. Figure 4B offers a glimpse at the diverse range of forms taken by the segregation profiles within the study area, but with so many data points (25 rasters x 36,000 locations x 3 Census years = 2.7 million records), it is important to find alternative means of representing the data.

[Figures 4A and 4B]

From $\widetilde{H}_{pd}$ we can fit $\breve{H}_{pd}$ using Equation 6 and then generate our four key descriptive variables using the conversions shown in Equation 7. If we take these four variables: *initial intensity, neighborhood size, decay, and limit,* for all three census years we can focus our analysis on the elements of the functional form that have theoretical relevance for processes that are important for describing neighborhoods. A number of possibilities exist for grouping these functional forms and future research will need to explore the impact of different choices in how to group observations. However, for the purposes of this analysis the partitioning algorithm PAM (Partitioning Around Medoids see Kaufman & Rousseeuw, 2009 for a complete description) was used on the four variables to identify clusters of similar functional forms. PAM works from a distance matrix generated from the four variables and the choice of four clusters is justified by both a quantitative examination of fit statistics (the “silhouette” in Kaufman and Rousseeuw’s terminology) and by visual inspection (the analysis explored partitions of between 2 and 35 clusters to arrive at this conclusion). Figure 5, a “fishbone plot” shows the distribution of the values of $\widetilde{H}_{pd}$ for each of the four clusters that result from the PAM algorithm. For descriptive clarity I have named these four clusters *standard, flat, steep, and rising.*

[Figure 5 about here]

While the clustering algorithm is mechanistic in its determination of appropriate clusters, a visual review of the clusters it identifies suggests some important properties of each that may enhance our capacity to understand what is going on when we see them mapped on the study area in the next section.

- *Standard:* As its name suggests, this cluster references the fact that we expect segregation measures to be higher at smaller geographic scales, and, by definition, our measure $\widetilde{H}_{pd}$ goes to zero for large values of *d*. The functional forms in this cluster conform to this general pattern.
- *Flat:* The functional forms in the *flat* cluster look remarkably similar to the *standard* cluster in Figure 5, but have a somewhat lower *initial intensity* and a larger *neighborhood size* as we can see in Figure 6 below. This cluster of functional forms exhibits less variation with scale than expected. The characteristics of places where population measures do not change with scale provides an opportunity to better understand those places that do.

- *Steep:* This cluster signifies the presence of spatially compact clusters of homogenous population such as those described for North Beacon Hill in the introduction of this paper. This functional form features a high *initial intensity,* a small *neighborhood size,* and a steep *decay.* With a median *neighborhood size* of 2,500 feet (.76 km), the *steep* functional form represents small-scale segregated places that play a key role in supplying the diversity of the larger South Seattle region.
- *Rising:* The final cluster shown in Figure 5 has negative values for *initial intensity* and rises to meet the regional average with larger values of d in $\widetilde{H}_{pd}$. This cluster captures places that are fully integrated at very small scales and represents a relatively rare residential settlement pattern in U.S. cities.

Figure 6 offers a second look at how differences in the key elements of the functional form went into dividing records into four distinct clusters. The figure has one panel for each of the four key elements: *initial intensity, limit, decay,* and *neighborhood size.* Within each panel are boxplots, one for each of three decades for each of four clusters: *standard, flat, steep,* and *rising*. The comparison of boxplots by cluster and parameter helps draw attention to the differences between clusters; while the *standard,* and *flat* clusters look fairly similar in Figure 5, the differences in *initial intensity,* and *neighborhood size* stand out in this visualization. The clustering function works from the combined pool of records from all three census years, so that we can undertake meaningful comparisons of change in functional form across years. Separating the boxplots out by decade lets the reader see that, while there are differences within clusters across years, those differences are not so significant that, for example, only records from 2010 have the properties of necessary to be included in a particular cluster—each of the clusters can be found in significant quantities within each decade.

In looking at the clusters in Figures 5 and 6 it is important to recognize that these clusters are specific to the study area. Other functional forms are certainly possible, most notably we would expect to see areas with high *initial intensity* and large values for *neighborhood size* in most places where broader spatial patterns of segregation are prevalent. It is likely that we could see such patterns simply by extending our study area a few miles north. Nevertheless, in the remarkably diverse neighborhoods of South Seattle, large area segregation does not occur. The four clusters shown here tell a very specific story about the kinds of places that exist in South Seattle. It will require additional work in other kinds of places before we can develop a complete typology of functional forms.

Now that we have identified the key elements of the functional form that may be relevant for describing multi-scalar segregation and used those elements to identify descriptive clusters we face the challenging task of interpreting our findings. In particular, if we are to attribute significance to these clusters and to the key elements of functional form that we used to generate them, then we need to represent these clusters in space and examine how they change over time.

Mapping Functional Forms for South Seattle: 1990-2010

Having identified a reasonable typology for examining multi-scale segregation functional forms, the next step is to see how these forms cluster in space and to try to identify patterns of transition between functional forms both across space and over time.

Figure 7 maps the four categories across all three census decades. All three panels in Figure 7 show a predominance of the *standard* functional form as we would expect. It is important to acknowledge that $\widetilde{H}_{pd}$ is a relative measure, so that the 0 value used throughout the analysis would likely be quite diverse when compared to results for most other contexts. Nevertheless, we see an expected pattern for residential settlement in this diverse region across all three census years; we have some degree of segregation at small scales (likely reflecting broader correlations between housing stock, socio-economic characteristics, and historical patterns), trending towards a diverse *milieu.* We can see this functional form decreasing in prevalence through the southern portion of our study area in the 1990 to 2000 time period and increasing in the North Beacon Hill neighborhood in the 2000 to 2010 time period (see Figure 3 for neighborhood names and boundaries).

[Figure 7 about here]

While the maps in Figure 7 convey a wealth of information, space requires that we focus on only a few of the key elements. Transitions in and out of the *steep* cluster are one element of Figure 7 that merits consideration. The study period captures a timeframe in which the Central District (the northern most neighborhood shown in Figure 7) went from predominantly Black (~52% Non-Hispanic Black in 1990) to predominantly White (~55% Non-Hispanic White in 2010). In practice, smaller areas within the neighborhood were much more segregated than those numbers suggest. The *steep* functional form in that neighborhood picks up the extreme segregation at small scales in that neighborhood in 1990 when some blocks were virtually all Non-Hispanic Black and again when some of those same blocks were virtually all Non-Hispanic White by 2010. Key to understanding the rapid transition from *steep* to *steep* in this neighborhood is the expansion and movement of the *rising* and *flat* functional forms in the eastern portion of the neighborhood. These clusters appear to capture the extension of the relatively integrated areas in the downtown core as Whites moved into the area in the 90's and 00's. An important lesson from this transition is that the *rising* and *flat* functional forms have the potential to signify the period of transitional diversity understood to be characteristic of gentrifying neighborhoods (Card, Mas, & Rothstein, 2008; Lee, 1985; Schelling, 1971). We also observe the *steep* functional form expanding significantly in Mid and South Beacon Hill, reflecting a transition in this neighborhood as this portion of the region continued to be a preferred location of a burgeoning Asian population. The decline of the *steep* functional form in North Beacon Hill from 2000 to 2010 reflects an increased entry by Hispanics and Non-Hispanic Whites into this portion of the region in the latter decade of the study.

The *rising* functional form is of particular interest in the context of this research because racial/ethnic integration at very small geographic scales is traditionally associated with a "tipping point" period of neighborhood transition (Card et al., 2008) but several scholars have noted that South Seattle appears to feature a stable form of this integration (Cashin, 2004; Gordon et al., 1998; Lee, 1985). The *rising* functional form appears, at least anecdotally, to support the tipping point thesis, rather than pointing to something more stable. Only the small spatial cluster in the Central District appears in two time periods, and as discussed above, this was associated with the most dramatic example of gentrification in the study area. The *rising* cluster that appears on the North Edge of Columbia City in 2000 is also associated with a recognized site and time of gentrification. Noting that this area shows as *standard* in both 1990 and 2010 suggests that the transition in and out of the *standard* functional form requires further examination.

If we move away from a consideration of specific clusters and explore the patterns on display in Figure 7 it seems clear that the administrative boundaries of the neighborhoods hold a great deal of variation within them. Moreover, our discussion of the transitions in the Central District and Columbia City neighborhoods suggest that the clusters mapped in this Figure may be as interesting for what they say about the likelihood of transition in a place as they are for describing a place at a given time. Taking these pieces of information together, it seems inappropriate to try and treat these clusters as being in any way representative of neighborhoods themselves, though future research will need to explore ways in which the information contained in the segregation profile can be leveraged in this way.

Discussion

The intent of this article has been to lay out an argument for the conceptualization of population measures as multi-scalar. I have presented a set of methods for characterizing functional forms in terms that have theoretical relevance within a multi-scalar framework as well as a technique for categorizing variation in these functional forms. Nevertheless, the analysis presented in the previous section only scratches the surface of the potential applications of multi-scalar segregation both in terms of how segregation can be represented and how its representation can inform research on neighborhood change and neighborhood effects. In this section I will address three key issues going forward: the identification of neighborhoods, the study of neighborhood change (in time) and the study of spatial diffusion. I will also comment on the difficulties that the complexity of these functional forms presents for further research.

A key reason for working with very small geographic areas is to delineate the reasonable boundaries for neighborhoods that may contribute to a broader set of literatures on neighborhood effects. Spielman and Logan (2013) contribute significantly in this regard by building up neighborhoods as spatial clusters based on congruencies in population measures built up from individual-level data, but much more remains to be done; both in building neighborhoods for current data, and leveraging the information in the segregation profile to more accurately delineate boundaries.

Several aspects of the functional form considered here appear to be useful in the development of appropriate neighborhood boundaries. First, grouping small areas based on similarities in profile allows for the delineation of places that are similar rather than just homogeneous. This is increasingly important as diverse places become the focus of research and decisions to bound places based on a homogeneous population become less useful. Second, some characteristics of the functional form, particularly the *neighborhood size* variable described here, would appear useful in identifying the 'center' of a neighborhood (areas within a cluster for which the *neighborhood size* variable is the largest). Conversely, these same characteristics might help designate areas that are peripheral to the neighborhood. This graduated membership might be useful in characterizing neighborhoods as having fuzzy boundaries, and consequently varied effects on residents. This fuzzy membership aligns well with empirical research showing that people's conceptions of neighborhood boundaries are fairly fluid (Clapp & Wang, 2006; Jenks & Dempsey, 2007; Lynch, 1960). Subsequent research will develop these ideas of neighborhood membership based on segregation profiles with the explicit aim of testing whether these representations can contribute to the literature on neighborhood effects.

A second area where a multi-scalar conception of segregation can contribute to neighborhood-level research is in the representation of neighborhood change over time. Neighborhood change and stability are key topics in urban geography and urban sociology; at the heart of literatures on segregation and gentrification among many others. To date, most research on these topics conceptualizes change in terms of percentile shifts in, for example, race or occupation. The segregation profile has the potential to augment our understanding of these processes by locating change at specific scales. Further research needs to better understand how consistent change is across scales. Specifically, given two segregation profiles for the same place in two time periods, where along the x axis (local environment size) does change occur? Does change in broader local environments increase the intensity of change at local environments (pressure builds), or does the presence of broad changes slow down the pressure to change at small scales (many places changing means individual places change more slowly)? Do gentrifying places experience change at broad scales or narrow scales or both? Does segregation towards ethnic enclaves exhibit the same kinds of change or is it more focused? Differences in the scale at which places experience change can be useful in identifying places that are at risk of change, and it may help us understand why some places remain stable (for better or worse). Future work will look at patterns of change in segregation profiles over time and compare it with change in other variables that can be represented as multi-scalar profiles (e.g. median home price, median income, poverty status).

A final area for development of research using multi-scalar segregation measures may lie in the analysis of processes of diffusion with respect to neighborhood change. We know that neighborhoods have momentum and that both improvement and decline of neighborhoods follow spatial patterns that are frequently represented by diffusion or contagion models (Rey & Anselin, 2011; van Ham et al., 2012). Multi-scalar segregation may help us represent how processes are transmitted. By looking at change with respect to neighboring areas we may be better able to understand the scale of gentrification effects (e.g. how big an area is likely to gentrify at once or what regions are likely to gentrify next) we might also be able to estimate the speed with which certain processes of neighborhood change are likely to travel. The *decay* variable discussed above may be particularly useful in understanding the characteristics of places that are particularly susceptible or resistant to change.

People experience segregation at multiple scales and those experiences, from their home to the regional labor market, operate simultaneously and in concert with one another to impact opportunities. It is clear from the literature that segregation, as with many population measures, is associated with a 'neighborhood effect,' but it is also clear that the basis for that effect is both larger than and smaller than the neighborhood itself. Moving away from a 'correct' scale of analysis for studying neighborhood change opens up a host of new opportunities for understanding how and why neighborhoods change and how they influence the people who live in or near them. Multi-scalar segregation can be an important step in recognizing both the broader context and narrower scope of the changes that impact neighborhoods.

References

Anselin, L. (1989). What is Special About Spatial Data? Alternative Perspectives on Spatial Data Analysis. NCGIA Technical Paper.

Auyero, J., & Swistun, D. A. (2009). *Flammable: Environmental Suffering in an Argentine Shantytown*. Oxford: Oxford University Press.

Bourgois, P. (2003). *In Search of Respect: Selling Crack in El Barrio* (Second.). New York: Cambridge University Press.

Card, D., Mas, A., & Rothstein, J. (2008). *Are Mixed Neighborhoods Always Unstable? Two-Sided and One-Sided Tipping* (No. 14470).

Cashin, S. (2004). *The failures of integration: How race and class are undermining the American dream*. New York: Public Affairs.

Clapp, J. M., & Wang, Y. (2006). Defining neighborhood boundaries: Are census tracts obsolete? *Journal of Urban Economics*, *59*(2), 259–284. doi:10.1016/j.jue.2005.10.003

Clark, W. A. V. (2005). Intervening in the residential mobility process: neighborhood outcomes for low-income populations. *Proceedings of the National Academy of Sciences*, *102*(43), 15307–12. doi:10.1073/pnas.0507308102

Duncan, O., Cuzzort, R., & Duncan, B. (1961). *Statistical geography: Problems in analyzing areal data. Statistical geography: …*. Glencoe, IL: The Free Press.

Duncan, O., & Duncan, B. (1955). A methodological analysis of segregation indexes. *American Sociological Review*, *20*(2), 201–217.

Ellen, I. G., & Turner, M. A. (1997). Does neighborhood matter? Assessing recent evidence. *Housing Policy Debate*, *8*(4), 833–866. doi:10.1080/10511482.1997.9521280

Ellis, M., Wright, R., & Parks, V. (2004). Work Together, Live Apart? Geographies of Racial and Ethnic Segregation at Home and at Work. *Annals of the Association of American Geographers*, *94*(3), 620–637. doi:10.1111/j.1467-8306.2004.00417.x

Farrell, C. R. (2008). Bifurcation, Fragmentation or Integration? The Racial and Geographical Structure of US Metropolitan Segregation, 1990--2000. *Urban Studies*, *45*(3), 467–499. doi:10.1177/0042098007087332

Fischer, C. S., Stockmayer, G., Stiles, J., & Hout, M. (2004). Distinguishing the Geographic Levels and Social Dimensions of U.S. Metropolitan Segregation, 1960-2000. *Demography*, *41*(1), 37–59.

Fischer, C. S., Stockmayer, G., Stiles, J., & Hout, M. (2004). Distinguishing the Geographic Levels and Social Dimensions of U.S. Metropolitan Segregation, 1960-2000. *Demography*, *41*(1), 37–59. doi:10.1353/dem.2004.0002

Freeman, L. (2009). Neighbourhood Diversity, Metropolitan Segregation and Gentrification: What Are the Links in the US? *Urban Studies*, *46*(10), 2079–2101. doi:10.1177/0042098009339426

Gentleman, R., & Lang, D. T. (2007). Statistical Analyses and Reproducible Research. *Journal of Computational and Graphical Statistics*, *16*(1), 1–23.

Goering, J. (2013). Neighborhood Effects and Public Policy. *City & Community*, *12*(1), 13–20. doi:10.1111/cico.12006

Gordon, A., Locke, H., & Ulberg, C. (1998). Ethnic Diversity in Southeast Seattle. *Cityscape*, *4*(2), 197–219.

Grengs, J. (2013). Reevaluating Poverty Concentration With Spatial Analysis: Detroit in the 1990's. *Urban Geography*, *28*(4), 340–360. doi:10.2747/0272-3638.28.4.340

Holloway, S. R., Wright, R., & Ellis, M. (2012). The Racially Fragmented City? Neighborhood Racial Segregation and Diversity Jointly Considered. *The Professional Geographer*, *64*(1), 63–82. doi:10.1080/00330124.2011.585080

Jenks, M., & Dempsey, N. (2007). Defining the neighbourhood: challenges for empirical research. *Town Planning Review*, *78*(2), 153–178.

Kaufman, L., & Rousseeuw, P. (2009). *Finding groups in data: an introduction to cluster analysis*. John Wiley & Sons.

Latham, A. (2002). Retheorizing the Scale of Globalization: Topologies, Actor-networks, and Cosmopolitanism. In A. Herod & M. Wright (Eds.), *Geographies of Power: Placing Scale* (pp. 115–144). Oxford: Blackwell.

Lee, B. A. (1985). Racially mixed neighborhoods during the 1970s: Change or stability? *Social Science Quarterly*, *66*(2), 346–364.

Lee, B. A., Reardon, S. F., Firebaugh, G., Farrell, C. R., Matthews, S. A., & O'Sullivan, D. (2008). Beyond the census tract: Patterns and determinants of racial segregation at multiple geographic scales. *American Sociological Review*, *73*(5), 766–791.

Leventhal, T., & Brooks-Gunn, J. (2003). Moving to opportunity: an experimental study of neighborhood effects on mental health. *American Journal of Public Health*, *93*(9), 1576–1582.

Lynch, K. (1960). *The image of the city*. Cambrdge, Massachusetts: MIT Press.

Maly, M. T. (2000). The Neighborhood Diversity Index: A Complementary Measure of Racial Residential Settlement. *Journal of Urban Affairs*, *22*(1), 37–47. doi:10.1111/0735-2166.00038

Maly, M. T. (2005). *Beyond Segregation: Multiracial and multiethnic neighborhoods in the United States*. Philadelphia: Temple University Press.

Marston, S. (2000). The social construction of scale. *Progress in Human Geography*, *24*(2), 219–242.

Massey, D. (2005). *For Space*. London: Sage.

Massey, D. S., & Denton, N. A. (1988). The Dimensions of Residential Segregation. *Social Forces*, *67*(2), 281–315. doi:10.1093/sf/67.2.281

Matthews, S. A. (2008). The salience of neighborhood: some lessons from sociology. *American Journal of Preventive Medicine*, *34*(3), 257–9. doi:10.1016/j.amepre.2007.12.001

Meegan, R., & Mitchell, A. (2001). "It"s Not Community Round Here, It's Neighbourhood': Neighbourhood Change and Cohesion in Urban Regeneration Policies. *Urban Studies*, *38*(12), 2167–2194. doi:10.1080/00420980120087111

Monkkonen, P., & Zhang, X. (2014). Innovative measurement of spatial segregation: Comparative evidence from Hong Kong and San Francisco. *Regional Science and Urban Economics*, *47*, 99–111.

Morrill, R. L. (1991). On the measure of geographical segregation. *Geography Research Forum*, *11*(1), 25–36.

Nyden, P., Maly, M., & Lukehart, J. (1997). The emergence of stable racially and ethnically diverse urban communities: A case study of nine US cities. *Housing Policy Debate*, *8*(2), 491–534.

O'Sullivan, D., & Wong, D. W. S. (2007). A Surface-Based Approach to Measuring Spatial Segregation. *Geographical Analysis*, *39*(2), 147–168. doi:10.1111/j.1538-4632.2007.00699.x

Openshaw, S. (1977). A geographical solution to scale and aggregation problems in region-building, partitioning and spatial modelling. *Transactions of the Institute of British Geographers*, *2*(4), 459–472.

Openshaw, S., & Taylor, P. (1979). A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In N. Wrigley (Ed.), *Statistical applications in the Spatial Sciences*. London: Pion.

Östh, J., Clark, W. A. V., & Malmberg, B. (2014). Measuring the Scale of Segregation Using k - Nearest Neighbor Aggregates. *Geographical Analysis*. doi:10.1111/gean.12053

Osth, J., Malmberg, B., & Andersson, E. (2014). Analysing segregation with individualized neighborhoods defined by population size. In C. D. LLoyd, I. Shuttleworth, & D. Wong (Eds.), *Social-Spatial Segregation: Concepts, Processes and Outcomes*. Policy Press.

Parisi, D., Lichter, D. T., & Taquino, M. C. (2011). Multi-Scale Residential Segregation: Black Exceptionalism and America's Changing Color Line. *Social Forces*, *89*(3), 829–852. doi:10.1353/sof.2011.0013

Pred, A. (1984). Place as historically contingent process: Structuration and the time-geography of becoming places. *Annals of the Association of American Geographers*, *74*(2), 279–297.

Reardon, S. F., & Bischoff, K. (2011a). Income Inequality and Income Segregation. *American Journal of Sociology*, *116*(4), 1092–1153.

Reardon, S. F., & Bischoff, K. (2011b). More unequal and more separate: growth in the residential segregation of families by income, 1970–2009. *Report Prepared for the Russell Sage US2010 Project*.

Reardon, S. F., Farrell, C. R., Matthews, S. A., O'Sullivan, D., Bischoff, K., & Firebaugh, G. (2009). Race and space in the 1990s: Changes in the geographic scale of racial residential segregation, 1990–2000. *Social Science Research*, *38*(1), 55–70. doi:10.1016/j.ssresearch.2008.10.002

Reardon, S. F., & Firebaugh, G. (2002). Measures of Multigroup Segregation. *Sociological Methodology*, *32*(1), 33–67. doi:10.1111/1467-9531.00110

Reardon, S. F., Matthews, S. A., Sullivan, D. O., Lee, B. A., Firebaugh, G., Farrell, C. R., & Bischoff, K. (2008). The Geographic Scale of Metropolitan Racial Segregation. *Demography*, *45*(3), 489–514.

Reardon, S. F., & O'Sullivan, D. (2004). Measures of spatial segregation. *Sociological Methodology*, *34*(1), 121–162.

Rey, S., & Anselin, L. (2011). Measuring spatial dynamics in metropolitan areas. *Economic Development Quarterly*, *25*(1), 54–64. doi:10.1177/0891242410383414

Sampson, R. J. (1997). Neighborhoods and Violent Crime: A Multilevel Study of Collective Efficacy. *Science*, *277*(5328), 918–924. doi:10.1126/science.277.5328.918

Sampson, R. J., Morenoff, J. D., & Gannon-Rowley, T. (2002). Assessing "Neighborhood Effects": Social Processes and New Directions in Research. *Annual Review of Sociology*, *28*(1), 443–478. doi:10.1146/annurev.soc.28.110601.141114

Schelling, T. (1971). Dynamic Models of Segregation. *Journal of Mathematical Sociology*, *1*(2), 143–186.

Spielman, S. E., & Logan, J. R. (2013). Using High-Resolution Population Data to Identify Neighborhoods and Establish Their Boundaries. *Annals of the Association of American Geographers*, *103*(1), 67–84. doi:10.1080/00045608.2012.685049

Van Ham, M., Manley, D., Bailey, N., & Simpson, L. (2012). *Neighbourhood Effects Research: New Perspectives*. Springer Netherlands.

Wang, Y. (2012). Decomposing the entropy index of racial diversity: in search of two types of variance. *Annals of Regional Science*, *48*(3), 897–915.

Wilson, W. J. (1987). *The truly disadvantaged: The inner city, the underclass, and public policy*. Chicago: University of Chicago Press.

Woldoff, R. (2011). *White flight/black flight: The dynamics of racial change in an American neighborhood*. Ithaca: Cornell University Press.

Wong, D. W. S. (1993). Spatial Indices of Segregation. *Urban Studies*, *30*(3), 559–572. doi:10.1080/00420989320080551

Wong, D. W. S. (2003). Implementing spatial segregation measures in GIS. *Computers, Environment and Urban Systems*, *27*(1), 53–70. doi:10.1016/S0198-9715(01)00018-7

Wong, D. W. S. (2005). Formulating a General Spatial Segregation Measure. *The Professional Geographer*, *57*(2), 285–294. doi:10.1111/j.0033-0124.2005.00478.x

Wong, D. W. S. (2010). Location-Specific Cumulative Distribution Function (LSCDF): An Alternative to Spatial Correlation Analysis. *Geographical Analysis*, *33*(1), 76–93. doi:10.1111/j.1538-4632.2001.tb00438.x

Wong, D. W. S., Reibel, M., & Dawkins, C. J. (2007). Introduction—Segregation and Neighborhood Change: Where are we After More Than a Half-Century of Formal Analysis 1. *Urban Geography*, *28*(4), 305–311. doi:10.2747/0272-3638.28.4.305

Figures

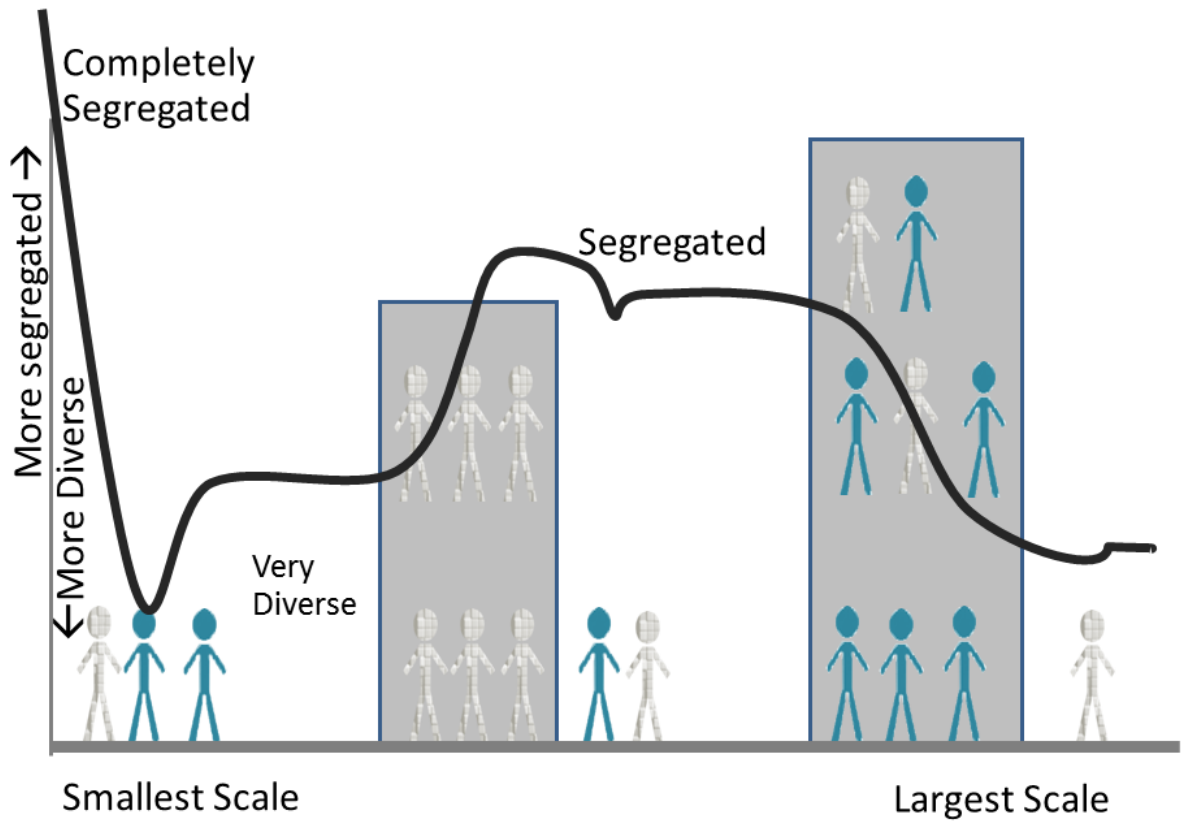

Figure 1: Schematic diagram of the level of segregation $\widetilde{H}_{pd}$ as a function of scale

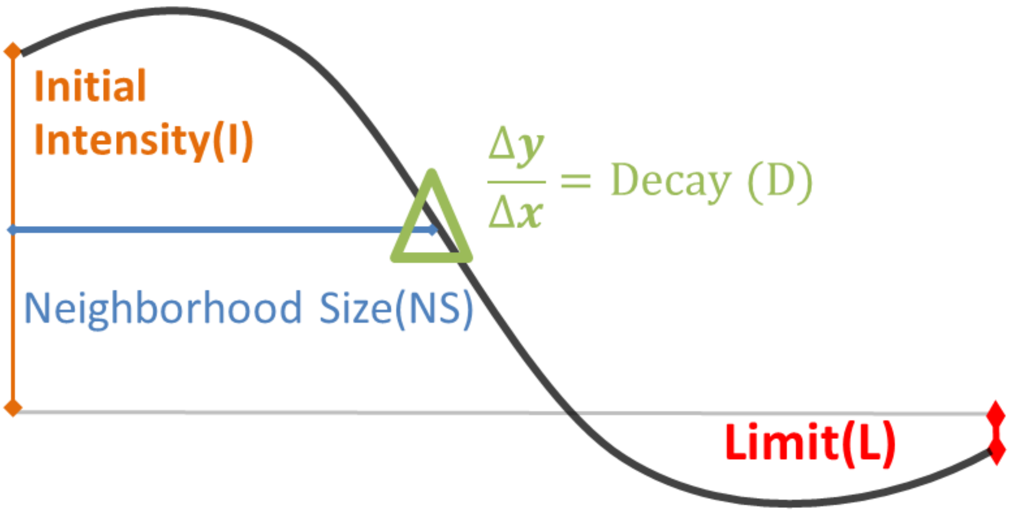

Figure 2: Segregation profile conceptualized as an exponential function with four key variables

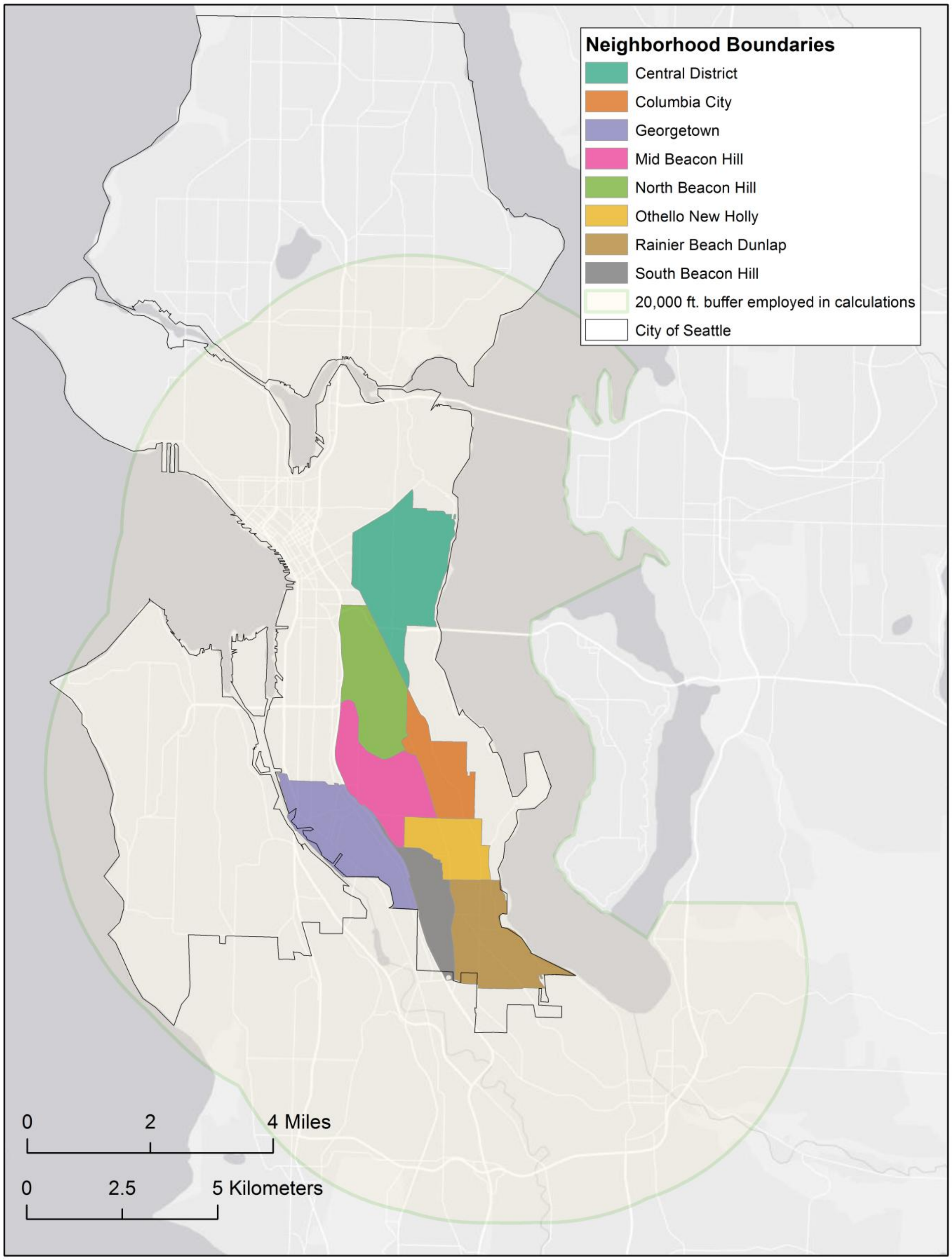

Figure 3: South Seattle study area with neighborhoods and calculation boundary

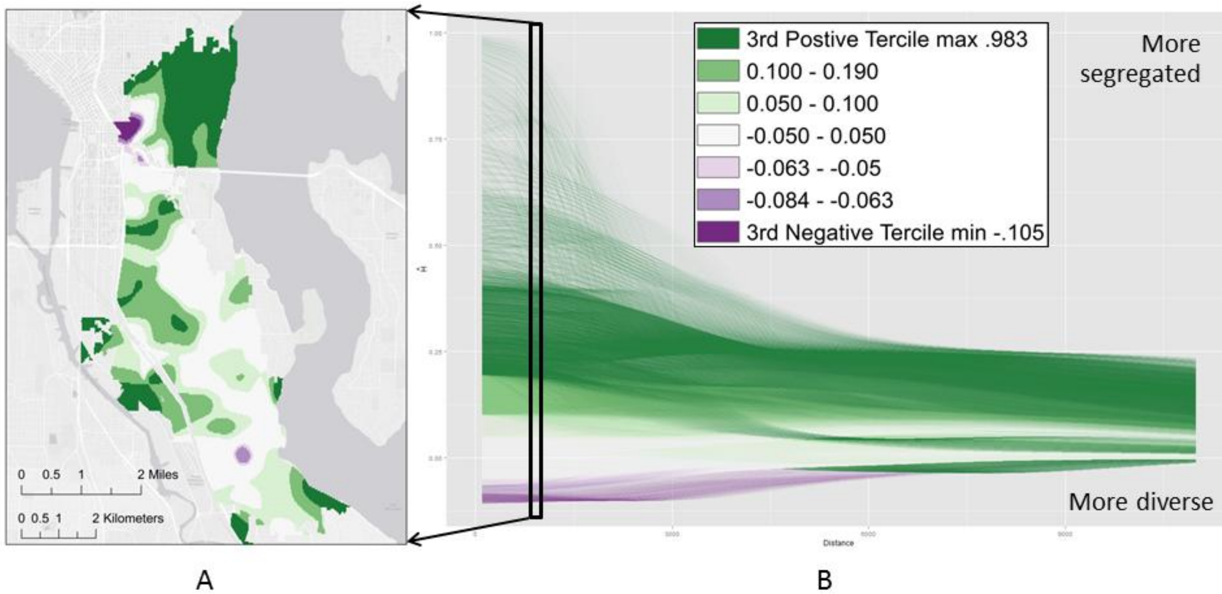

Figure 4: (A) $\tilde{H}_{p600ft.}$ for 1990 (B) $\tilde{H}_{pd}$ for 1990

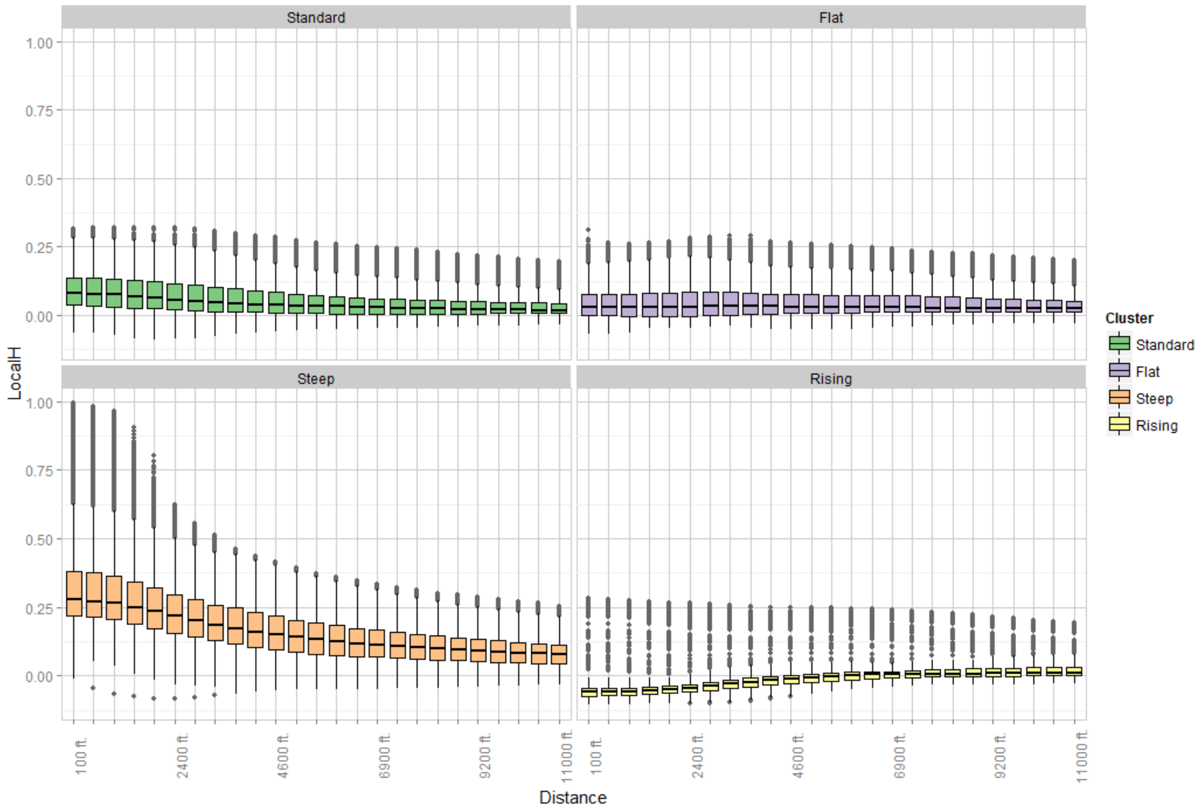

Figure 5: Fishbone plot showing distribution of values of $\tilde{H}_{pd}$ within clusters

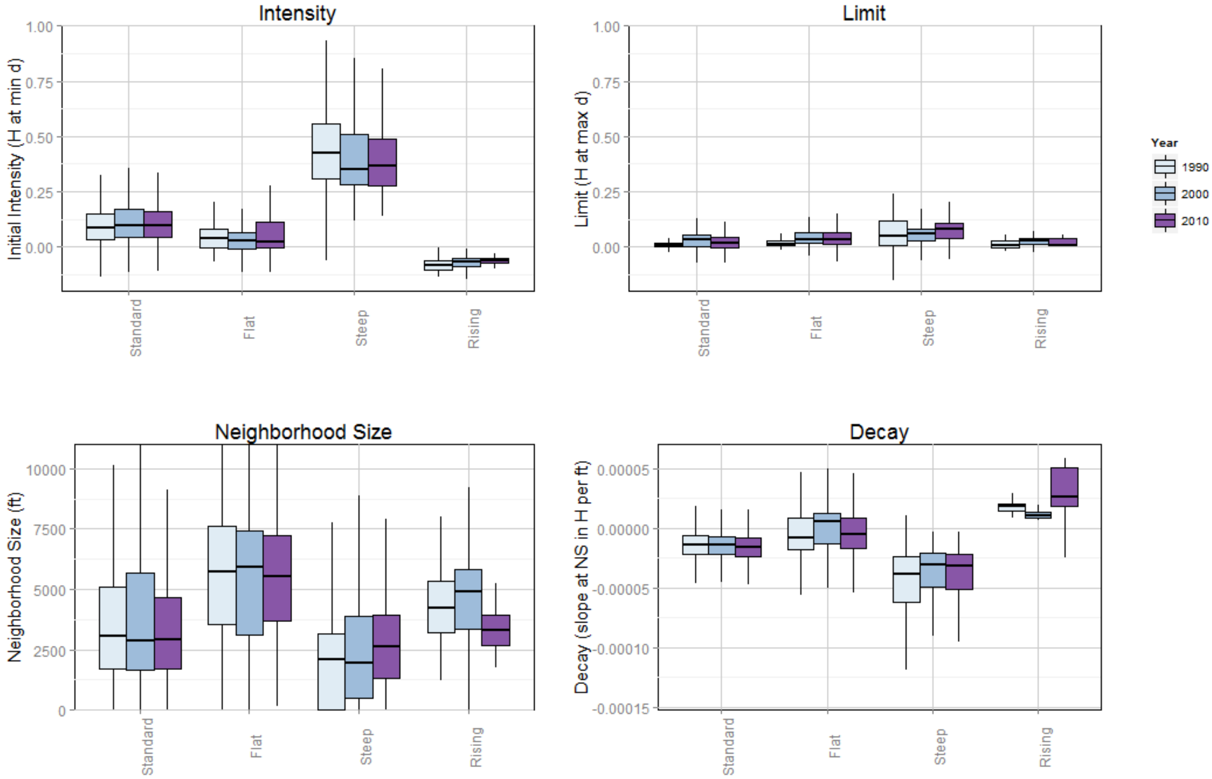

Figure 6: Distribution of parameter values by cluster and census year.

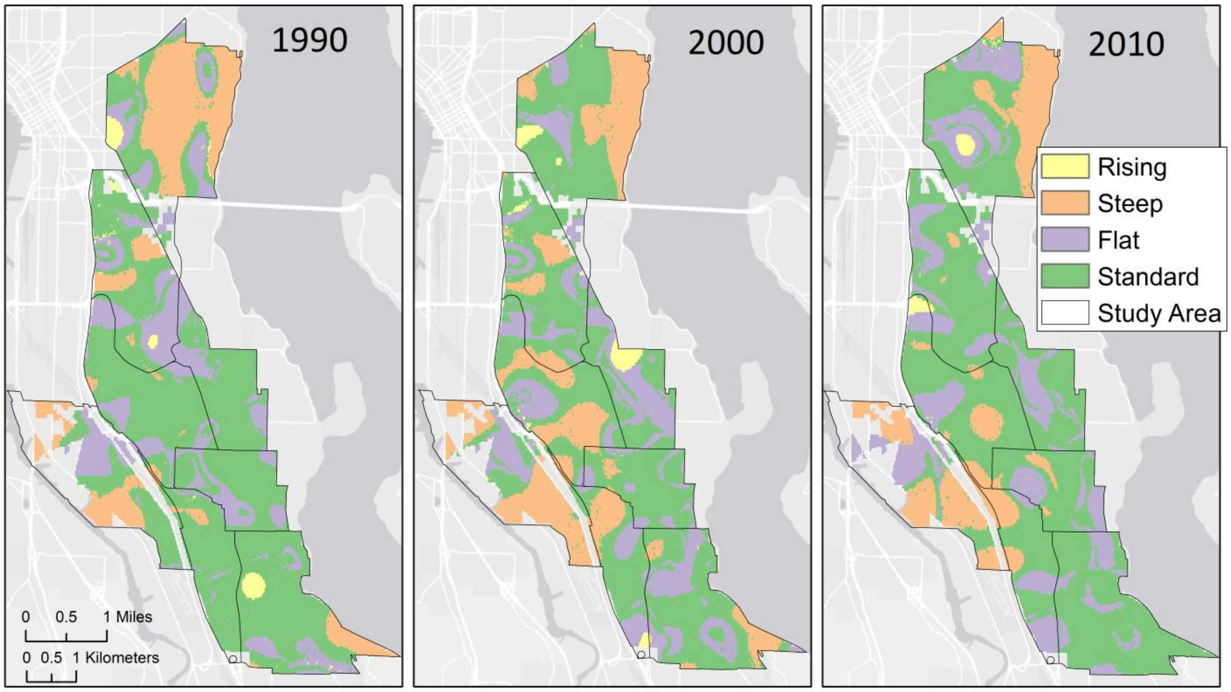

Figure 7: Typology of functional forms across decades