

Which came first, people or pollution? A review of theory and evidence from longitudinal environmental justice studies

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Paul Mohai^{1,3} and Robin Saha²¹ School of Natural Resources and Environment University of Michigan Ann Arbor, MI 48109 734-763-4598, USA² Department of Environmental Studies University of Montana Missoula, MT 59812 406-243-6285, USA³ Author to whom any correspondence should be addressed.E-mail: pmohai@umich.edu and robin.saha@mso.umt.edu**Keywords:** environmental justice, environmental racism, environmental disparities, longitudinal studies, racial disparities, environmental justice theory, environmental justice evidence**Abstract**

A considerable number of quantitative analyses have been conducted in the past several decades that demonstrate the existence of racial and socioeconomic disparities in the distribution of a wide variety of environmental hazards. The vast majority of these have been cross-sectional, snapshot studies employing data on hazardous facilities and population characteristics at only one point in time. Although some limited hypotheses can be tested with cross-sectional data, fully understanding how present-day disparities come about requires longitudinal analyses that examine the demographic characteristics of sites at the time of facility siting and track demographic changes after siting. Relatively few such studies exist and those that do exist have often led to confusing and contradictory findings. In this paper we review the theoretical arguments, methods, findings, and conclusions drawn from existing longitudinal environmental justice studies. Our goal is to make sense of this literature and to identify the direction future research should take in order to resolve confusion and arrive at a clearer understanding of the processes and contributory factors by which present-day racial and socioeconomic disparities in the distribution of environmental hazards have come about. Such understandings also serve as an important step in identifying appropriate and effective societal responses to ameliorate environmental disparities.

Environmental justice has become firmly established in the academic literature. In the past two decades, hundreds of journal articles and books have been published on this topic across multiple disciplines. Systematic reviews of quantitative studies confirm the existence of racial and socioeconomic disparities in the distribution of a wide variety of pollution and environmental hazards (Mohai and Bryant 1992, Lester *et al* 2001, Ringquist 2005). At the same time, fears about the health consequences and other quality of life impacts along with concerns about the justice implications of disproportionate environmental burdens have spawned a social movement and considerable public policy efforts around this issue (Taylor 2000, Brulle and Pellow 2006, Bullard *et al* 2011). The existence of racial and socioeconomic disparities in the distribution of environmental burdens has led to searches for explanations of why and how these disparities have come about. Understanding the causes of such

disparities has not only been of interest to academics but also to policy makers who seek solutions to environmental injustices.

A variety of theoretical explanations of the causes of environmental disparities have been offered that take into account economic, sociopolitical, and racial-discriminatory factors. These are discussed more fully below. An important step toward understanding the causes of environmental disparities is to establish the general processes by which the disparities occur. It is understood that these disparities may have come about in one of two ways: (1) at the time of siting, hazardous waste sites, polluting industrial facilities, and other locally unwanted land uses (LULUs) have been disproportionately placed near where minorities and poor people live; or (2) demographic changes after siting have led to increasing concentration of minorities and the poor around these sites (Oakes *et al* 1996, Been and Gupta 1997, Pastor *et al* 2001, Mohai

et al 2009a, Pais *et al 2014*). For ease of discussion, we refer to the first process as ‘disparate siting’ and the second process as ‘post-siting demographic change’. To date, which of these two processes occurs, or whether both occur, has not been firmly established. Most analyses of environmental disparities have been cross-sectional, snapshot studies that employ census and environmental data at only one point in time. A necessary step for understanding how the present-day disparities came about is to conduct longitudinal analyses that examine the demographic characteristics at hazardous site locations at the time of siting and then examine demographic changes at these locations after siting. However, relatively few longitudinal studies exist, and those that exist have often led to confusing and contradictory findings.

For example, some studies have found statistically significant evidence for the disparate siting hypothesis (Shaikh and Loomis 1999, Pastor *et al 2001*, Saha and Mohai 2005), while others have not (Oakes *et al 1996*, Been and Gupta 1997). Evidence to support the post-siting demographic change hypothesis has been similarly mixed, with some studies finding no statistically significant support (e.g., Oakes *et al 1996*, Been and Gupta 1997, Hunter *et al 2003*) and others finding at least some support (Hipp and Lakon 2010). One possible reason for the inconsistency in findings may be due to the mix of geographic scopes of these longitudinal studies. In fact, some studies have been national-level (e.g. Been and Gupta 1997, Oakes *et al 1996*, Hunter *et al 2003*), while others have been state-level (Saha and Mohai 2005) or metropolitan-level (Shaikh and Loomis 1999, Pastor *et al 2001*, Hipp and Lakon 2010).

However, these studies have also applied different methodological approaches. The earliest quantitative environmental justice studies, both cross-sectional and longitudinal, applied what has been referred to as the ‘unit-hazard coincidence’ approach, in which the demographic characteristics of geographic units (typically census tracts or zip code areas) ‘hosting’ hazardous sites are compared with the demographic characteristics of the non-host units (Mohai and Saha 2006, 2007, Chakraborty *et al 2011*). Not taken into account by this approach is the precise location of the hazard within the host unit. Therefore the unit-hazard coincidence method does not consider whether the hazard inside the host unit is near the center, off-center, or near a boundary. If near a boundary, the hazard may impact not just the host unit alone but nearby units, as well. If there is a disproportionate concentration of poor people and people of color near the hazardous site, then these disproportionate concentrations may also exist in the nearby units. Mohai and Saha (2006, 2007) found that for the nation’s commercial hazardous waste facilities, application of the unit-hazard coincidence method leads to an underestimation of the degree of racial and socioeconomic disparities around such facilities when compared to using methods where the precise locations of the

facilities are determined and their distances to nearby census block groups, census tracts, and zip code areas are taken into account. Mohai and Saha termed these methods distance-based methods, examples of which are discussed later in this paper. Given that employing unit-hazard coincidence and distance-based methods leads to contrasting findings in cross-sectional analyses, the contrasting findings in existing longitudinal studies may also be the result of employing these differing methods.

Given the mix of theoretical explanations, methods, findings, and conclusions drawn from existing longitudinal environmental justice studies, our goal in this paper is to review this body of literature in order to make sense of it and to identify future directions for research. Specifically, in the following we review the theoretical explanations of disparate siting and post-siting demographic change, examine and discuss methods for testing these explanations, review the evidence, and draw conclusions about what directions future research needs to take in order to get us closer to understanding the processes by which racial and socioeconomic disparities in the distribution of environmental hazards come about. We begin with a discussion of theoretical explanations.

Explanations of disparate siting and post-siting demographic change

If present day racial and socioeconomic disparities in the distribution of environmental hazards are the result of disparate siting or the result of post-siting demographic changes (or both), what drives these processes? Three categories of explanations have been proposed: economic, sociopolitical, and racial discrimination (Saha and Mohai 2005, Mohai *et al 2009a*). These explanations apply to both disparate siting and post-siting demographic change. Although the various explanations can be conceptualized as distinct and are presented as such below, in actuality the categories may be inter-related (Mohai *et al 2009a*). Considering the separate categories of explanations is nevertheless useful for parsing out and investigating the complex social processes believed to be involved with facility siting and post-siting demographic change.

Economic (i.e., market dynamics) *explanations* have been perhaps the most frequently cited to account for disparate siting (see, e.g., Mohai and Bryant 1992, Anderton *et al 1994*, Been and Gupta 1997, Downey 1998). They involve the argument that a pattern of placing hazardous waste and polluting industrial facilities disproportionately in poor people and people of color communities results from industries’ desire to lower the costs of doing business. Because new hazardous waste and polluting industrial facilities require land, whose purchase may incur a significant expense, industries will seek to locate new facilities where land prices are low and where transportation

infrastructure and adequate labor pools are nearby. These areas tend to be where poor people and people of color also live.

Sociopolitical explanations of disparate siting involve the argument that industries seek the 'path of least resistance' (Bullard and Wright 1987, Pastor *et al* 2001, Saha and Mohai 2005). Industries are aware that the siting of noxious facilities may result in local opposition by residents. Such opposition may generate bad publicity for the company or delay the start of projects. Thus industries seek to place new facilities in communities where opposition will be minimal or ineffective. These will be where residents are perceived to have few resources and little political clout. Such residents tend to be disproportionately poor and people of color. Furthermore, the long latency period between when toxic exposures and the most serious health effects such as cancer occur may result in an acquiescence to what Nixon (2011) refers to as 'slow violence'.

Regarding *racial discrimination explanations*, there is debate whether racial animus is involved in siting noxious facilities in people of color communities. Even if such animus does not exist, the demographic characteristics of a community may be used to profile and target communities as the 'paths of least resistance' for new facilities (Bullard and Wright 1987, Cole and Foster 2001). People of color communities may also be disproportionately targeted because of what has been termed 'side-effect' discrimination (Feagin and Feagin 1986, Mohai *et al* 2009a), i.e., discrimination in one area of institutional actions leading to discriminatory outcomes in another, even if there is no intent to discriminate in the latter. For example, racialized zoning and property laws and various related practices, such as racially restrictive covenants, in the early to middle 1900s involved the intent to segregate the races and place industrial facilities in people of color communities (Rabin 1989, Pulido *et al* 1996, Cole and Foster 2001, Taylor 2014). The practices of credit rationing, also known as redlining, whereby financial institutions denied minorities housing loans in predominantly white areas, and steering, whereby realtors directed minorities exclusively into predominantly non-white neighborhoods, helped create segregated housing and land use patterns that served to put people of color in close proximity to industrial zones targeted for new sitings (Bullard *et al* 1994). Present-day decisions to place new industrial facilities in areas zoned industrial, on the other hand, may not involve a deliberate intent to discriminate. However, because of past discriminatory zoning decisions, new facilities will nevertheless tend to be sited disproportionately where people of color live. Furthermore, such communities over time may come to be seen as 'sacrifice zones', encouraging further siting of noxious facilities (Lerner 2010).

Economic explanations of post-siting demographic change involve the argument that the siting of noxious

facilities triggers the move-out of affluent residents and the move-in of the poor (Mohai and Bryant 1992, Oakes *et al* 1996, Been and Gupta 1997, Pastor *et al* 2001, Pais *et al* 2014). Noise, blight, odors, concerns about health impacts, declining property values, social stigma, and other negative quality of life impacts will motivate residents to leave, but it is affluent residents who are more able to purchase more expensive properties in neighborhoods with relatively high environmental quality. Poor people and people of color (because they are disproportionately poor) will be left behind. Furthermore, because the noxious facility will depress property values, housing in the neighborhood may become more affordable thus attracting more poor people and people of color to move-in. Over time, the poor and people of color may become more concentrated in the neighborhood while whites become less so.

A *sociopolitical explanation* of disproportionate post-siting demographic change argues that post-siting demographic changes induced by the above negative quality of life impacts may be accelerated further in those communities with ethnic heterogeneity, low social capital and resources (Pastor *et al* 2001, Sobotta *et al* 2007). Communities with few civic organizations, neighborhood associations, and leaders may have limited ability to effectively participate in various forms of civic engagement such as advocating for environmental compliance and enforcement of facility operations (Zahran *et al* 2008, Schelly and Stretesky 2009). Caught in a vicious cycle, the community may become vulnerable to increasing pollution, more unwanted facilities, degrading infrastructure, loss of small businesses and local services, and further demographic change as quality of life, property values, and social capital decline ever further (Elliott and Frickel 2013).

Racial discrimination explanations of post-siting demographic change involve the argument that economic and sociopolitical factors alone do not account for widening disparities in the concentration of people of color and whites after noxious facilities have been sited. Housing discrimination and segregation also play a role (Mohai and Bryant 1992, Pastor *et al* 2001, Pais *et al* 2014). Even when people of color have the financial means to buy into environmentally more desirable neighborhoods, discrimination in the housing market may limit their options as to where they can move and thus keep people of color concentrated in polluted neighborhoods, while whites are more able to leave (Morello-Frosch and Jesdale 2006, Taylor 2014).

Although we have presented distinct categories of explanations, the institutional and systemic nature of racism and its deeply-embedded nature in various sectors of society, such as housing and labor markets, education, transportation, food systems, health care, land use planning, environmental regulation and enforcement, can make separating out race as distinct factor a strictly theoretical exercise (Bonilla-

Silva 1997, Feagin 2006). Thus, racial explanations for both disparate siting and post-siting demographic change can intersect with economic and sociopolitical explanations and even be viewed as imbued within them (Mohai *et al* 2009a).

Evidence of disparate siting and post-siting demographic change

There are only two previous national-level studies of which we are aware that have tested both the disparate siting and post-siting demographic change hypotheses. Both examined hazardous waste treatment, storage and disposal facility (TSDF) locations (Oakes *et al* 1996, Been and Gupta 1997, also see Mohai and Saha 2015 in this issue, not reviewed here). Both employed the unit-hazard coincidence approach. Neither study found compelling evidence to support either hypothesis.

For example, Oakes *et al* (1996 p 137) found that ‘panel comparisons of TSDF tracts to other communities with similarly higher levels of industrial employment across all available census data for the last three decades [1970, 1980, and 1990] do not support the claim that TSDFs, in particular, are systematically sited in minority or poor communities’. They also found no evidence to support the argument that TSDFs result in post-siting demographic changes that lead to present-day racial and socioeconomic disparities in the distribution of hazardous waste TSDFs. Indeed, Oakes *et al* found no statistically significant differences between African American percentages in host and non-host tracts in a cross-sectional analysis of facility location using the most recent census at the time (i.e. 1990). Furthermore, no statistically significant differences were found in the Hispanic percentages between samples of host and non-host tracts examined. However, statistically significant disparities were found for some of the socioeconomic variables.

With some exceptions, Been and Gupta’s (1997) findings are largely similar to those of Oakes *et al*. Like Oakes *et al*, Been and Gupta found no evidence of disparate siting of hazardous waste TSDFs in tracts that were disproportionately African American in 1970, 1980, or 1990, causing them to conclude that their study (p 33):

‘... provides no significant evidence ... that the percentage of African Americans in a tract at the beginning of a decade affected the probability that the tract would be selected to host a facility sometime in that decade. Thus, the evidence provides little support for the claim that siting processes follow a PIBBY—Put In Blacks’ Backyards—strategy, at least as to sitings in the last twenty-five years’.

Although they did find some evidence that TSDFs tended to be placed in census tracts that were disproportionately Hispanic in 1970, Been and Gupta did not find any evidence of disparate siting of TSDFs in

tracts with disproportionate numbers of Hispanics in 1980 or 1990. Been and Gupta also did not find any evidence that TSDFs were sited in tracts that were disproportionately poor. In fact, they found that poverty rates were a negative predictor of which tracts were likely to be selected as hosts for a TSDF. Furthermore, Been and Gupta found little evidence of post-siting demographic changes by either racial or socioeconomic characteristics. They concluded (p 29) that: ‘In sum, the study does not support the argument that market dynamics following the siting of a TSDF change the racial, ethnic, or socioeconomic characteristics of host neighborhoods’.

The only other longitudinal environmental inequality analyses of which we are aware that have tested both the disparate siting and post-siting demographic change hypotheses are those by Shaikh and Loomis (1999) and by Pastor *et al* (2001). Both are sub-national in scope.

Like the earlier national-level studies, Shaikh and Loomis used the unit-hazard coincidence method, in this case to match the locations of polluting industrial facilities to zip code areas in the Denver area. However, unlike the Oakes *et al* (1996) and Been and Gupta (1997) studies, Shaikh and Loomis found statistically significant evidence to support the disparate siting hypothesis. However, racial disparities between host and non-host zip codes were not as great as socioeconomic disparities, and controlling for socioeconomic characteristics generally eliminated the statistical significance of race as a predictor of which zip codes were to receive new facilities and which ones not. At the same time, Shaikh and Loomis found little evidence to support the post-siting demographic change hypothesis.

In contrast to the earlier studies which employed the unit-hazard coincidence approach, Pastor *et al* (2001) used distance-based methods to analyze demographic characteristics within 0.25 mile and 1.0 miles of locations destined for hazardous waste TSDFs in the Los Angeles area. Like Shaikh and Loomis, they found statistically significant evidence to support the disparate siting hypothesis. However, in contrast to Shaikh and Loomis, they found the racial composition of the locations to be a stronger predictor than socioeconomic characteristics of which locations were to receive a TSDF and which not. They also found that areas where minority percentages were increasing *before* siting tended to attract new TSDFs. Indeed, they found that even areas where the absolute percentage of minorities was not changing, but one group was replacing another (a process they refer to as ‘ethnic churning’), tended to attract new TSDFs, as did areas with low homeownership. However, Pastor *et al* did not find evidence that minorities and the poor tend to move to where TSDFs were located *after* siting. They concluded from these results that minorities and the poor tend to attract hazardous waste TSDFs, rather than TSDFs attract minorities and the poor. In other

words, the disparate siting hypothesis was supported by the evidence, but the post-siting demographic change hypothesis was not.

We are not aware of other longitudinal studies that have tested both the disparate siting and post-siting demographic hypotheses. However, several other longitudinal studies exist and we review them below for the insights they provide pertaining to these two hypotheses.

Saha and Mohai (2005), for example, examined patterns of disparate siting of TSDFs in Michigan but did not examine post-siting demographic changes. They examined patterns of TSDF siting over a much longer time period than previous studies, going back as far as the 1950s. Like Pastor *et al* (2001), Saha and Mohai employed distance-based methods in comparing host and non-host areas within and beyond 1.0 mile of hazardous waste TSDFs. They found a historical pattern in that racial and socioeconomic disparities in TSDF siting did not emerge until the 1970s, became intensified in the 1980s, and persisted in the 1990s. They note that the 1970s and 1980s were periods of heightened environmental awareness and concerns fueled by environmental crises such as the Love Canal crisis and rising white NIMBYism. Minority and low-income communities became increasingly targeted for hazardous waste facilities and other LULUs over this period because industry came to recognize that such communities lack the political resources and clout of more affluent white communities.

Although we are not aware of other quantitative longitudinal studies that have examined the disparate siting hypothesis, there are three additional studies that have relevance in understanding the post-siting demographic change hypothesis. These include the studies by Hunter *et al* (2003), Hipp and Lakon (2010), and Pais *et al* (2014). As with the studies examining the disparate siting hypothesis, these studies have produced mixed findings, although findings supporting the post-siting demographic change hypothesis have generally tended to be weaker.

Hunter *et al* (2003) examined the post-siting demographic change hypothesis, but not the disparate siting hypothesis. Their study was national in scope and employed the unit-hazard coincidence method. They examined whether the number of commercial hazardous waste facilities, Superfund sites, and total air emissions from large industrial emitters at the county level predicted the outmigration of whites, blacks, Asians, and Hispanics from the county. They found no significant relationship between the quantities of these environmental hazards and outmigration. They concluded (p 37) that: '...the results presented here do not provide evidence of selective migration patterns as a factor in the social distribution of environmentally hazardous facilities'.

Hipp and Lakon (2010) also examined only the post-siting demographic change hypothesis. Their

study focused on six counties in Southern California and employed distance-based methods. They examined the demographics of residential populations within 1.0 mile of polluting industrial facilities. They weighted these facilities by the quantity and toxicity of their air emissions. For the period between 1990 and 2000, they found that disparities in toxic air emissions exposures were highest for Hispanics, followed by Asians, and then by African Americans. They found that Hispanic disparities in exposures remained consistently high over the 10 year period with no appreciable increases or declines. For African-Americans, disparities increased somewhat, while for Asians disparities declined over this period. Socioeconomic disparities also declined over the 10 year period, but persisted. Overall, then, Hipp and Lakon did not find appreciable widening of racial and socioeconomic disparities in exposure to air pollution. Most disparities declined though persisted over the 10 year period.

Pais *et al*'s (2014) study uses a unique approach and provides indirect evidence for the post-siting demographic change hypothesis. Rather than looking at changes in the demographics around hazardous sites over time using census data, they examined the moves over time of individual black and white respondents participating in the Panel Study of Income Dynamics (PSID). They estimated average industrial air pollution burdens for all the census tracts in which PSID respondents lived between 1991 and 2007. They found that white households who frequently moved in this time period tended to move to tracts with successively less pollution while black households who frequently moved tended to move to tracts with successively more pollution. Racial disparities in these patterns persisted even when controlling for socioeconomic differences between groups. Although Pais *et al* did not examine the demographics of the tracts affected by high levels of pollutions directly, their findings nevertheless suggest that the tendency of white households that move to move to less polluted neighborhoods and the tendency of black households that move to move to more polluted neighborhoods will increase racial disparities in environmental exposures over time.

Qualitative and mixed methods studies

Qualitative and mixed methods studies, including detailed historical analyses and ethnographic studies of cases of urban decline and development, also offer evidence pertaining to disparate siting and post-siting demographic change. These case studies tend to focus on a single or small number of facilities in one or a few places, but often include statistics and other evidence of demographic conditions at the time of siting, and some include evidence related to neighborhood change processes over time. Thus, these studies

provide detailed though somewhat anecdotal support for various explanations described above.

Many of these studies consider the siting process and report minority populations being present at the time of siting, in some cases for many decades beforehand. For example, studies of a vast industrial area in Louisiana describe the siting of a major concentration of petrochemical factories during the 1960s, 1970s and 1980s in various rural African American enclaves inhabited by descendants of freed slaves (Roberts and Toffolon-Weiss 2001, Lerner 2005). Other studies document the prior existence of minority and low-income communities in describing the creation of industrial zones in cities and the role of land use planning in creating such patterns. For example, Pellow (2002) describes how the northern migration of African Americans after Reconstruction concentrated them in South Chicago, which later became industrialized following WWII. He also describes how NIMBY reactions in other parts of Chicago resulted in the placement of various wastes in the South Side (also see, e.g., Hersh 1995, Pulido *et al* 1996, Szasz and Mueser 2000, Montrie 2005, for similar accounts of Los Angeles, California, Pittsburgh, Pennsylvania, Memphis, Tennessee, and San Jose, California, respectively).

Nearly all of these studies found support for various nuanced racial discrimination explanations of disparate siting; for example, the racially motivated establishment of industrial zones in and next to minority communities and the effect of housing segregation in concentrating minorities in areas where they could be targeted for siting of noxious facilities (see e.g., Pulido 2000). This latter explanation highlights racial discrimination that occurred prior to siting to explain patterns of disparate siting. A few studies report overt discrimination in siting in recent decades, for example the case of Dickson, Tennessee, and racial explanations have also been offered in infamous cases of siting of hazardous waste landfills in Sumter County, Alabama, and Warren County, North Carolina (Bullard and Wright 2012).

The case studies also support economic and sociopolitical explanations. Various studies point to perceived economic benefits of industrial development in communities with limited development options (see, e.g., Lerner 2010 and the cases of Tallevast, Florida, and Addyston, Ohio; and Pellow 2002 and the case of Rollins, Illinois). Such communities may welcome industry and thereby limit their own ability to successfully oppose future new siting proposals. Indeed, many studies of citizen action describe the challenges faced by communities with limited political clout and provide strong support for sociopolitical explanations (Szasz 1994, Camancho 1998, Crawford 1996, Cole and Foster 2001, Roberts and Toffolon-Weiss 2001, Allen 2003).

Very few case studies either examine or provide support for post-siting demographic change, in part,

because the study designs rarely include gathering and analyzing longitudinal data needed to make such assessments. One study of the spatio-temporal distribution of air pollution in heavily-industrialized Gary, Indiana, found that '[w]heras in 1950 all classes and races shared the burdens of particulate pollution fairly equally, by 1980, blacks and low income residents suffered disproportionately' (Hurley 1988 p 6). Affluent whites moving away from pollution sources resulted in a strengthening association between pollution levels and race and socioeconomic variables over time. Overall the case literature is too scant to offer much evidence regarding the existence of post-siting demographic change.

Distance-based versus unit-hazard coincidence methods

As the literature review above indicates, evidence to support the disparate siting and post-siting demographic change hypotheses has been mixed. Only four prior studies of which we are aware have tested both, and only two of these have been national in scope. These two national-level studies employed the unit-hazard coincidence method and found very weak evidence to support either the disparate siting or post-siting demographic change hypotheses. Mohai and Saha (2006, 2007) provided a detailed examination of the unit-hazard coincidence method and demonstrated why this approach tends to underestimate racial and socioeconomic disparities around hazardous sites compared to distance-based methods. The underestimation of such disparities may explain the weak evidence for disparate siting and post-siting demographic change hypotheses obtained by Oakes *et al* (1996) and Been and Gupta (1997). Mohai and Saha and others (see, e.g., Chakraborty *et al* 2011) who have conducted critical examinations of environmental justice methodologies have called for replacing the unit-hazard coincidence method in proximity-based environmental disparity studies with distance-based methods. These methods take into account the precise geographic location of the hazard within the host unit and the distance of the hazard to nearby non-host units. A growing number of environmental disparities studies have begun using distance-based methods. Although a number of variations of distance-based methods exist, two that have received wide attention are the 50% areal containment (Anderton *et al* 1994, Davidson and Anderton 2000, Mohai and Saha 2006) and areal apportionment methods (Glickman 1994, Chakraborty and Armstrong 1997, Hamilton and Viscusi 1999).

In applying the 50% areal containment method, the boundary of the host neighborhood of an environmental hazard is determined by combining all the geographic units where at least 50% of the area of the unit is captured by a radius of fixed distance from the

hazard. The populations within the captured units are then combined and their demographics contrasted with those of the units not captured. In applying the areal apportionment method, the boundary of the host neighborhood is a perfect circle within a fixed distance from the hazard. The population within this circle is determined by combining the populations of all the units intersected by the circle. Each unit's contribution is weighted by the proportion of its area captured by the circle. For example, if 75% of the unit's area is captured, then 75% of its population is allocated, etc. The demographics of the combined weighted populations of the units within the circle are then contrasted with the demographics of the population beyond the circle. Mohai and Saha (2007) found that the areal apportionment method produces especially reliable estimates of the demographic characteristics near hazardous waste TSDFs, the estimates tending to be consistent whether census block groups, census tracts, or zip codes are used as the building block units for the circular areas around the TSDFs.

Given Mohai and Saha's (2006, 2007) findings, we believe more longitudinal studies employing distance-based methods at varying geographic scopes need to be conducted to see if application of such methods - and similar methods that better account for the precise location of environmental hazards and their proximity to nearby populations—will resolve the conflicting and inconclusive findings of earlier longitudinal environmental justice studies.

Conclusions

A considerable number of quantitative analyses have been conducted in the past several decades that demonstrate the existence of racial and socioeconomic disparities in the distribution of environmental hazards of a wide variety. The vast majority of these have been cross-sectional, snapshot studies employing data on the hazardous facilities and population characteristics at only one point in time. To fully understand how present-day disparities come about, longitudinal analyses are required that examine the demographic characteristics of sites at the time of facility siting and track demographic changes after siting. Such analyses can then be used to determine whether present-day disparities result from: (a) a pattern of disproportionately siting LULUs in poor and people of color communities at the time of siting; (b) demographic changes that lead to a disproportionate concentration of poor and people of color around such sites after siting; or (c) both processes. Identifying which processes occur is an important step in understanding the causes of present-day racial and socioeconomic disparities in the distribution of environmental hazards. There are several categories of theoretical explanations of the factors thought to drive these two processes, including economic,

sociopolitical, and racial discrimination. If the processes by which present-day disparities come about can be identified, then better means of testing hypotheses also could be devised to determine what factors drive these processes.

Unfortunately, few longitudinal environmental justice studies currently exist, and those that exist have led to confusing and even contradictory findings. Given Mohai and Saha's (2006, 2007) finding that the unit-hazard coincidence method leads to an underestimation of the degree of racial and socioeconomic disparities around hazardous sites, we believe that application of this method in longitudinal environmental justice studies is the principal reason for the inconclusive and conflicting findings about the disparate siting and post-siting demographic change processes. Given the paucity of longitudinal environmental justice studies to date, more longitudinal environmental justice studies are needed to determine whether the application of distance-based methods would lead to clearer and more definitive findings about the two processes thought to account for present-day racial and socioeconomic disparities around hazardous waste TSDFs. We believe there is an especially strong need for a national-level longitudinal environmental justice study that employs distance-based methods in order to determine (a) whether the results of such a study would contrast with the results of the national-level longitudinal studies employing the unit-hazard-coincidence method, and (b) whether these results would be more similar to those of the sub-national studies employing distance-based methods. Indeed, the findings from such a national-level study would not only help to clarify the patterns by which present-day environmental disparities come about, but they would also help to determine whether the contrasting findings of earlier studies have been the result of differing geographic scales or the differing methodologies. The results of one such national-level study are presented in our companion article in this issue (Mohai and Saha 2015).

Not only are more studies needed that apply better methods to account for the demographic characteristics around hazardous sites, future studies also need to assess disparate siting and post-siting demographic change hypotheses for a much wider range of sources of pollution and other forms of environmental risk, including power plants, industrial facilities, highways, railroad lines, power lines, brownfield sites and others. Furthermore, these sources of risk do not exist in isolation. Often times they are concentrated in specific neighborhoods and communities that some have termed 'sacrifice zones' (Lerner 2010). Longitudinal analyses that take into account the history of zoning and land use decisions thus also need to be incorporated into future studies to help explain the creation of such zones that then become magnets for further noxious facility siting (Saha and Mohai 2005, Taylor 2014).

Because of limitations on the availability of pollution data at fine geographic scales, future longitudinal studies could also make greater use of land use regression (LUR) models to characterize fine-scale air pollution exposures in a comprehensive manner over space and time (e.g., Novotny *et al* 2011, Clark *et al* 2014). Data inputs in such models include geographic characteristics such as population density, land use/land cover (based on satellite data), distance to roads, and pollution data available from the US Environmental Protection Agency's air pollution monitoring system and other sources. LUR models could be used to construct longitudinal data sets based on the satellite record initiated in 1973. Advantages of this approach include the ability to derive estimates of total outdoor air pollution exposure burdens and the potential to support comparative analyses across urban contexts internationally.

Finally, we also see potential in making greater use of individual/household-level survey data, such as have been done recently by Mohai *et al* (2009b), Crowder and Downey (2010), and Pais *et al* (2014). Surveys have several advantages over census data. Respondents can be represented as geographic points, leaving little ambiguity in determining whether they are located within specified distances of hazardous sites. Survey data also provide opportunities to obtain more extensive and detailed information about the life circumstances of people living near hazardous sites than are available from the census. With longitudinal surveys there is also the ability to track the moves of individuals representing various subpopulations to see whether environmental exposures increase, decrease, or remain stable over the life-course for the respective subpopulations. Nevertheless, neighborhoods, their population characteristics, resources, and the environmental hazards within them also change over time. Census boundaries are well-suited to efficiently capture such changes. To bring greater clarity to how environmental disparities come about, we thus believe longitudinal studies that employ ecological (census) data will also continue to be needed along with studies that use individual/household level (survey) data.

A better understanding of the processes by which environmental injustices come about is an important step in identifying the root causes of these injustices and the role that racial discrimination, market dynamics, and sociopolitical factors play. It is also necessary to develop appropriate and effective societal responses to ameliorate environmental disparities. New government policies, better application of existing laws, changes in industry practices, community empowerment and social movement building can help ensure fairness in the siting process and help prevent the development of inequitable and harmful distributions of risk after siting (Bullard *et al* 2007, 2008). Ultimately, success may require confronting structural inequalities at all levels.

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