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Superstorm Sandy and the Demographics of Flood Risk in New York City

Jacob William Faber[1]

Abstract "Superstorm Sandy" brought unprecedented storm surge to New York City neighborhoods and like previous severe weather events exacerbated underlying inequalities in part because socially marginalized populations were concentrated in environmentally exposed areas. This study makes three primary contributions to the literature on vulnerability. First, results show how the intersection of social factors (i.e., race, poverty, and age) relates to exposure to flooding. Second, disruption to the city's transit infrastructure, which was most detrimental for Asians and Latinos, extended the consequences of the storm well beyond flooded areas. And third, data from New York City's 311 system show there was variation in distress across neighborhoods of different racial makeup and that flooded neighborhoods remained distressed months after the storm. Together, these findings show that economic and racial factors overlap with flood risk to create communities with both social and environmental vulnerabilities.

Keywords Superstorm Sandy · Climate change · Vulnerability · New York City

Introduction

"Superstorm Sandy" posed an unprecedented threat to New York City. What began as a tropical depression in the Caribbean eventually combined with two winter storm systems to form one of the most destructive hurricanes in recorded history (Holthaus 2012). In addition, a full moon causing above average tides increased flood risk for low-lying neighborhoods (Drye 2012). In anticipation of the storm, New York City shut down the transit system relied upon by the majority of city workers for their commutes and ordered 375,000 individuals to evacuate flood-prone areas (Gibson 2012). Thousands of flights were cancelled (The Telegraph 2012) and the Stock Exchange closed (Associated 2012a). By the time Sandy reached the New Jersey shore on October 29, 2012 it had been downgraded from a Category 3 hurricane to a post-tropical cyclone, but it remained the largest storm of its type since the National Hurricane Center (NHC) started recording these events in 1988 (Santora 2013).

Wind, rain, and storm surge caused 43 deaths (Associated 2012c) and billions of dollars in damage to New York City (Bloomberg 2012; Superstorm Research Lab 2013). Tens of thousands of New Yorkers were left homeless (Grossman *et al.* 2012) while 800,000 lost electricity (The New York Times 2012). Days passed before the Metropolitan Transit Authority (MTA) reopened subways but service remained limited (Associated 2012b). Regional public transportation infrastructure was also severely damaged (CBS New York 2012a).

As the city limped back to normalcy in the weeks following the storm, some observed that Sandy's impact was not equally experienced across all communities. Those with means could afford a hotel or flee to a safer area outside the city, while many in low status occupations were trapped by disabled transit or had to work through the storm and its chaotic aftermath (Rohde 2012). Over 400 public housing buildings—home to almost 80,000 residents—lost electricity, elevators, heat, and hot water (Furman Center for Real Estate and Urban Policy 2013; Lipton and Moss 2012). Almost half of those who died due to Hurricane Sandy were over 65 (Chavkin 2013). Many of the schools able to reopen a week after the storm did so without heat (Hauser 2012).

✉ Jacob William Faber
jacob.faber@nyu.edu

[1] Department of Sociology, New York University, 295 Lafayette St., 4th Floor, New York, NY 10012, USA

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Previous severe weather events have exacerbated underlying social inequalities (Adeola and Stephen Picou 2012; Bolin and Stanford 1991; (Fussell *et al.* 2010; Hartman and Gregory 2006; Klinenberg 2002; Logan 2006; Sastrya and Gregory 2013; Sharkey 2007). Increasingly, scholars argue that analyses of environmental threats such as hurricanes must incorporate social factors (Adger 2006; Bolin 2007; Cutter 1996; Cutter *et al.* 2003; Wisner 2000, 2001) in order to understand two basic dynamics: the extent to which the geographic distributions of social and ecological vulnerability overlap; and how indicators of vulnerability such as poverty, minority status, or age lead to differences in experience of the same event. This study investigates how social structure shaped the threat posed by Hurricane Sandy in economically-polarized and racially-diverse—though segregated—New York City (Glaeser *et al.* 2008; Logan and Stults 2011). I begin by identifying which neighborhoods were most vulnerable to flooding, and then examine how the race, class, and age makeup of flooded neighborhoods compares to those that remained dry. Finally, I explore how disruptions to services, such as public transit, varied across neighborhoods in the wake of the storm.

Following a review of current research on social and environmental vulnerability, I describe the data and methods used to conduct an analysis of the demography of storm flooding within New York City. After presenting my results, I conclude with a discussion of how demographic differences in exposure to flood risk should be incorporated into preparedness plans for severe storms, which may become more common in the future for urban areas across the globe. I also make suggestions for a research agenda that can track recovery across neighborhoods.

Vulnerability: Environmental and Social

Since the 1990s a growing body of research has examined how characteristics such as race, income and age shape the experience of severe weather events and other ecological threats (Adger 2006; Cutter 1996; Cutter *et al.* 2003). This theoretical perspective posits that vulnerability is a function of exposure, sensitivity, and adaptation (Eakin and Luers 2006). Each of these components is tied to social inequalities, which can influence pre-disaster readiness, exposure during and resiliency in the wake of a disaster (Fothergill and Peek 2004). For example, segregation based on race may place households into low and high risk neighborhoods; the elderly may have difficulties evacuating due to health concerns; and wealth may enable families to relocate to less threatened areas (Cutter *et al.* 2003, Cutter *et al.* 2004; Dow 1992). Degree of social vulnerability determines who suffers permanent losses and who can rebuild after a severe weather event (O'Brien *et al.* 2006).

Several scholars have argued that vulnerability studies should be grounded in a political economy approach (Bolin 2007), which seeks to identify who is the most vulnerable and what characteristics make them vulnerable (Füssel 2007). Not only do social factors such as race, age and poverty shape migration and settlement patterns, but they also manifest as differences in political power that shape preparation for and responses to severe weather events (Wisner 2000, 2001). This is particularly important given the dramatic increase in inequality over the past several decades (Bolin 2007). Natural disasters have been overlooked as a source of stratification (Fothergill and Peek 2004), making the political economy approach necessary to understanding their full impact and to developing appropriate public policy to mitigate and adapt to climate change (Wisner 2000, 2001).

Much of this work involves mapping and related geostatistical techniques to examine whether and how the uneven distribution of social characteristics (e.g., poverty) overlaps with the distribution of environmental hazards (e.g., risk of flooding) (Cutter *et al.* 2004). (Fothergill and Peek 2004) argue that the poor in the United States are often located in particularly vulnerable places. The confluence of these two patterns was made clear in the wake of Hurricane Katrina, which had the greatest impact on New Orleans's black and poor population (Adeola and Stephen Picou 2012; Fussell *et al.* 2010; Hartman and Gregory 2006; Logan 2006; Sastrya and Gregory 2013; Sharkey 2007). While the most socially vulnerable places do not always coincide with the most ecologically threatened places, people living in areas facing dual vulnerabilities require special attention from policymakers responsible for disaster response and community resiliency (Cutter *et al.* 2004).

In addition to the spatial relationship between social and environmental vulnerabilities, this research seeks to understand how social factors create vulnerability to stressors (Füssel 2007). For example, in addition to the fact that the poor often live in more exposed communities, they typically reside in less resilient and more crowded housing units (Fothergill and Peek 2004). Which social factors are most important can also vary tremendously based on the types of threats a particular area faces. For example, a high density of commercial buildings may mean an area has a vibrant economy but also that it has a high potential for loss of economic assets in the case of an environmental disaster (Cutter *et al.* 2003).

A similar model has also appeared in related research of neighborhood effects. Recent work argues that any effect of neighborhood characteristics is a function of an individual's vulnerability, which can be driven by family structure, income, race, or numerous other factors (Galster 2012; Harding *et al.* 2011; Sharkey and Faber 2014; Small Mario and Jessica 2012).

Cities and Climate Change

While much public discussion of anthropogenic climate change has focused on global temperatures, rising sea levels and increased frequency and/or severity of hurricanes (Adger 2006; Dow 1992; Urry 2011) present a serious danger to coastal communities, particularly from flooding causing property damage, displacement, and death. For decades, natural disasters have been killing an increasing number of people and causing increasing economic damage (O'Brien *et al.* 2006). At the same time, more people are moving to urban areas (Ross 2011; Urry 2011) and coastal urban areas in particular (McGranahan *et al.* 2007; Hunt and Watkiss 2011; Dow 1992; White and Eugene Haas 1975).

The concomitant trends of urbanization and increased frequency and/or severity of hurricanes due to global climate change suggest that the city may become a more common environment in which extreme weather is experienced. (Hunt and Watkiss 2011) note that the literature on climate change impact and mitigation is increasingly focusing on cities for numerous reasons, including migration and the fact that any effects on cities are also likely to be felt in their surrounding regions. Cities are not only unique in their density and diversity, but they are also often sites of great inequality (Glaeser *et al.* 2008), suggesting the effects of severe weather may present unique challenges for them. Isolated pockets of poor residents, for example, could increase the difficulty of distributing social services in a time of crisis (Klinenberg 2002). Urban residents may also be more reliant on potentially vulnerable infrastructure, such as subways and bridges. [1]

New York City, which has rarely been struck by hurricanes, faced severe storms in the Atlantic hurricane seasons of 2011 (Irene) and 2012 (Sandy) (Holthaus 2012). This is perhaps suggestive of what may become a more regular occurrence as sea levels rise and storm frequency increases. It is the largest population center along the Atlantic coast (approx. 8,400,000 residents) as well as of enormous economic importance, meaning disruption of its infrastructure (transportation, in particular) is likely to have a significant impact (Hunt and Watkiss 2011; Kim 2012). How New York and other major population centers along the coast prepare for future hurricanes should be informed by what is learned from analysis of Sandy's impact.

This project describes the demographic characteristics of flooded neighborhoods in New York City and provides a model of how such a vulnerability analysis could be conducted in other cities. Understanding flood risk is perhaps the most important aspect of hurricane impact analysis. First, water is the most powerful force presented by a hurricane. Fast or even

slow-moving water has more potential to do damage to housing and infrastructure than wind and so is most likely to cause residential displacement and/or homelessness. Once the water recedes, flood-damaged homes and businesses often have to manage mold, which poses a health hazard (Nir 2013). Second, unless the physical contours of New York City and the surrounding waters change dramatically, some neighborhoods are likely to be flooded again in a similar or worse weather event. This descriptive analysis of the demographic characteristics of Hurricane Sandy's impact makes several contributions to the literature. First, it is important for scholars and policymakers to understand whether there were overlaps in the spatial distributions of social and environmental vulnerability in New York City. Second, the extent to which socially vulnerable populations experienced Hurricane Sandy in comparison to relatively privileged populations has critical implications for our understanding of equity and risk associated with natural disasters. Finally, little work to date has explored the consequences of climate change for transportation infrastructure (Hunt and Watkiss 2011).

Data and Methods

In the immediate aftermath of Hurricane Sandy, several individuals and organizations provided analyses of damage. For the most part, this work focused on the geographic characteristics of the storm's impact (see e.g., (Bloch *et al.* 2012)). I bring together several rich datasets to analyze Sandy's impact on New York City, taking a political ecology approach by identifying vulnerable populations and how vulnerability is manifested differently across groups. I focus specifically on race, income, and age, the most commonly accepted aspects of social vulnerability. (Bolin 2007; Cutter *et al.* 2003).

Operationalizing Risk

The Federal Emergency Management Agency (FEMA) provided shapefile data showing the extent of flooding caused by Sandy (FEMA 2012). I used GIS software to spatially merge FEMA's flood shapefile with census tract boundaries. Through this process, I was able to identify every census tract in New York City either as "dry," where centroids did not overlap with flood risk, or "flooded" if its centroid overlapped with the FEMA shapefile. This method was more conservative than associating flood risk with census tracts based on whether any part of a tract overlapped with flooding (i.e., an intersection method) in that some census tracts may have experienced severe damage outside the centroid. I chose the more careful strategy to avoid overstating claims about the storm's reach, since the intersection approach included more areas, particularly in the Bronx, Staten Island, and

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[1] For example, only 28 % of New Yorkers use a car to get to work (U.S. Census. Bureau 2012a), which has implications for evacuation plans.

Manhattan's West Side. Census tracts in these areas, which bordered a body of water, were in fact largely unaffected by the flooding indicated by FEMA data. The centroid-based approach also focuses the analysis on the most severely exposed neighborhoods. I then measured aggregate demographic differences across dry and flooded areas.

Demographic Data

I relied on the U.S. Census's American Community Survey 2007–2011 5-Year Sample (U.S. Census. Bureau 2012a) for information on poverty, racial makeup (non-Hispanic white, non-Hispanic black, non-Hispanic Asian, and Hispanic), age makeup (below 18 years old and above 65), and family structure (two parents, single mother, single father, or single parent of either gender) for every census tract in New York City. I used these data to calculate aggregate demographic characteristics across flood risks. For example, the percent white in dry census tracts was the total number of white residents in dry tracts divided by the total population in dry tracts:

$$\%\text{white}_{\text{DryTracts}} = \frac{\sum \text{White Population}_{\text{DryTracts}}}{\sum \text{Total Population}_{\text{DryTracts}}}$$

Transit Access

Little work has explored the consequences of climate change for transportation infrastructure (Hunt and Watkiss 2011). The New York City subway system, the seventh largest in the world, combined with a bus system that recorded over 670 million rides in 2011 provide the most popular method of transportation in all boroughs (Metropolitan Transportation Authority 2013; Schuerman 2013): 55 % of workers living in New York City rely on public transportation to get to work (U.S. Census Bureau 2012b).

I identified subway stations in New York City that were closed in the wake of the hurricane based on NYC Open Data (DoITT 2013a) and a map provided by the MTA (Yakas 2012). These data offer a broader picture of where vulnerabilities lie and what communities were affected. Using ArcGIS's Network Analyst package, I calculated the shortest walking distance to the nearest available subway stop for each census tract centroid both before and after the storm. I used a street map as the network along which paths traveled. In both calculations, paths were not allowed to cross water. Without this restriction, some census tracts were walking directly across the East River to get to the nearest subway station. I then estimated whether demographically-different neighborhoods experienced different degrees of transit disruption.

311

In 2004, New York City developed a centralized system through which individuals could telephone 311 to contact local government for non-emergency services. Callers can register a complaint, report a problem, or comment on local politician's performance. I gathered data from NYC Open Data on every 311 call made in 2012 (DOITT 2013b). The dataset included the date of the call, the location (address, longitude, and latitude), agency to which the call was directed, "complaint type" (e.g., electricity, air quality, heating, noise, etc.), and several other variables. I used these data to measure individuals' reported need for government assistance and assess how Hurricane Sandy affected this need. Thus, these data provide another estimate of the storm's impact and, through analysis of a time trend, insight into how the city government responded.

I focused primarily on the time periods preceding and following Hurricane Sandy (September 15 through December 31). For each day, I recorded the total number of 311 calls as well as separate counts for calls about electricity (complaint types Electric or Electrical), buildings (Boilers, Building Condition, Building/Use, Heating, Plumbing, Water System, or Dirty Conditions), trees (Damaged Tree or Dead Tree), or sewers (Sewer or Water System). Because call volume varies systematically over the course of a week (i.e., there are more calls on weekdays than weekends), I divided each day's volume by the average number of calls of a given type, for a given day of the week, for a given census tract, for February through December of 2012.[2] This provided each day's deviation from the average. I then examined how this deviation varied over time for areas that were flooded, for dry areas, and for the city overall.

Results

Flooding of New York City Neighborhoods

According to FEMA data, all five boroughs saw flooding, with the worst in Staten Island, southern Brooklyn, and the lower third of Manhattan (Fig. 1). Flooding also extended deep into northern Queens through Flushing Bay and Maspeth Creek. In addition, Red Hook, Coney Island, and The Rockaways were hard-hit in Brooklyn and Queens. Prior to the storm, the New York City Office of Emergency Management (OEM) warned that many of these communities would be under water and ordered evacuations for those most at risk—residents of Zone A (Huff 2012). In fact, OEM evacuation zones (Fig. 2) suggested flooding could have reached even further inland,

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[2] Due to apparent coding errors in the dataset calls from January 2012 were excluded.

Fig. 1 Hurricane Storm Surge in New York City
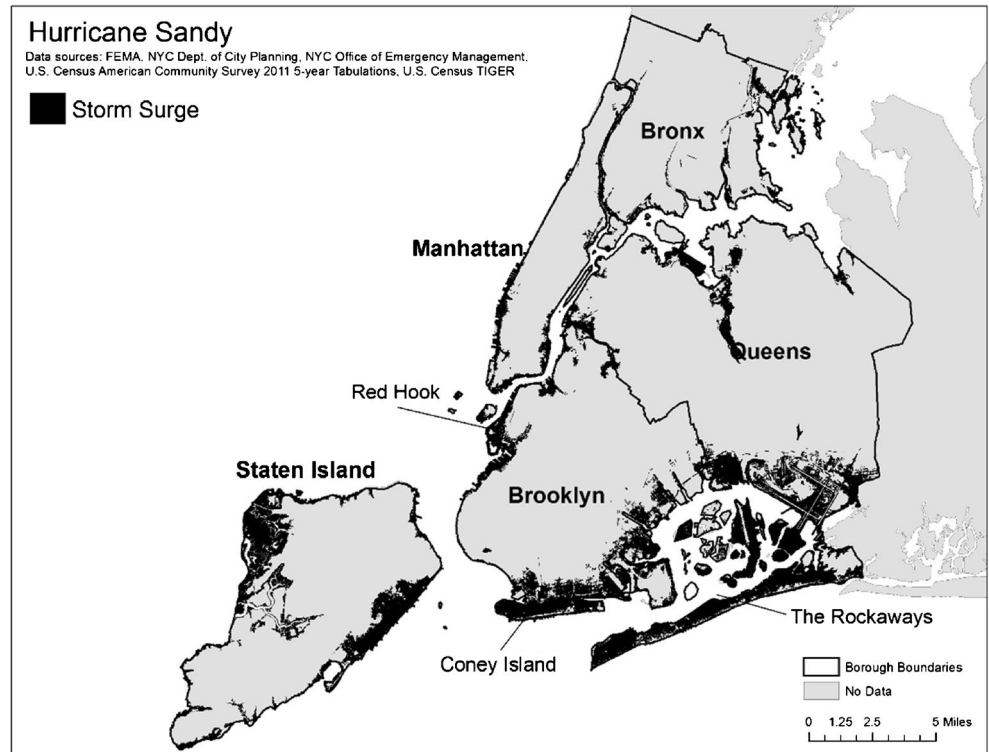
especially in Brooklyn and the Bronx, had the storm been more severe (Office of Emergency Managemen 2012). The accuracy of OEM's predictions varied across the city. In the event, flooding was largely restricted to Zone A, but in Brooklyn it crept well into presumably-safer Zone B.

OEM claimed that Zone A included all low-lying neighborhoods near water, which may experience flooding during *any* hurricane. Zone B included neighborhoods at risk of flooding from a hurricane of Category 2 or higher, while communities in Zone C should be inundated only in a Category 3

Fig. 2 NYC City Office of Emergency Management evacuation zones
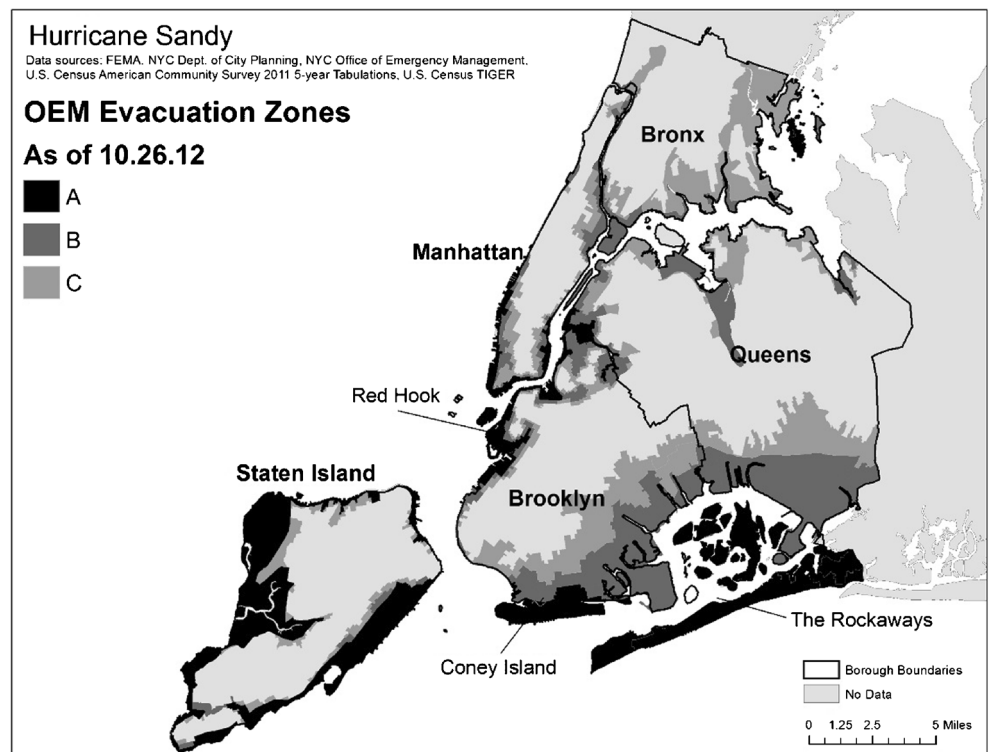
or 4 storm (Weisenthal 2012). Subsequent to Hurricane Sandy these demarcations have been replaced by a system with six categories of risk (Zones 1 through 6) (OEM 2014).

Hurricane Sandy's flooding reached 132 census tracts citywide, or 6.2 % of all tracts. Slightly more than half were in Brooklyn. On Staten Island, the hardest-hit borough, more than one in ten (10.2 %) census tracts were underwater, while fewer than one in 100 (0.9 %) were flooded in the Bronx. Here, again, there was a discrepancy between OEM predictions and flooding that actually occurred – especially in Brooklyn. More than 40 % of Brooklyn (44.9 %) and Manhattan (40.7 %) census tract centroids are within OEM evacuation zones; almost one third citywide. Over half a million (507,662) New Yorkers lived in flooded census tracts, while 2,392,082 lived in an OEM evacuation zone.

Analysis of racial and ethnic differences between flooded and dry areas revealed that census tracts with centroids within the storm surge were 43.2 % white, while those that did not experience any flooding were just over 30 % white (Fig. 3). Flooded tracts also had higher black representation (29.2 %) than dry tracts (24.8 %). Asian and Latino New Yorkers, on the other hand, were more likely to live in dry tracts. All of these differences were statistically significant: the z-scores for the proportional differences in white, black, Asian, and Latino populations were −151.9, −69.5, 108.2, and 145.3, respectively. Racial differences in flood risk could be due to the fact that the two hardest-hit boroughs, Staten Island (10.2 % of all census tracts flooded) and Brooklyn (9.2 %) are largely white and black, respectively. Manhattan (6.4 %) is almost half white. The least-flooded boroughs, the Bronx (0.9 %) and Queens (4.8 %), have sizeable Latino and Asian populations, respectively.

Children and the elderly are often the most impacted by environmental hazards (Cutter et al. 2003). Tracts directly affected by the surge were both older (percent over 65) and younger (percent below 18). Children are typically reliant on parents for caregiving and safety, particularly in emergencies. However, analysis of family structures across flood risk found

no difference in the percentage of families headed by a single parent between dry and flooded census tracts.

A larger percentage of the population was living below the poverty line in flooded tracts (18.7 %) compared to dry tracts (14.7 %). This difference was highly significant (z=−76.7) (Fig. 4). Only 44 of New York's 812 high-poverty census tracts were flooded (33 % all flooded tracts compared to 38.6 % of dry areas), most in Coney Island and Red Hook, Brooklyn (20 tracts) and The Rockaways, Queens (12). Poor flooded census tracts were home to 190,639 people.

For white and Asian New Yorkers, there were no statistically significant differences in poverty rates across flood risk. Among blacks and Latinos, however, the poverty rate was slightly, though significantly higher (z=−7.2 for blacks; z=−16.6 for Latinos) among those living in flooded areas, perhaps reflecting the fact that public housing complexes in Red Hook and Coney Island were flooded (Furman Center for Real Estate and Urban Policy 2013) (Fig. 5). The analysis of poverty rate differences by age group revealed that elderly populations in flooded communities had a higher poverty rate (22.2 %) than elderly populations in dry areas (18.0 %). Conversely, the child poverty rate was lower in flooded areas (25.0 %) than dry (28.4 %). Poverty rate differences were statistically significant for those over 65 (z=−18.3) and under 18 (z=24.1).

Looking at all three social factors (race/ethnicity, age, and poverty) sheds further light on the relationship between demographic characteristics and flood risk, particularly among white New Yorkers. The larger percent white in flooded tracts compared to dry tracts, as well as the lack of a difference in white poverty across flood risk could be interpreted as contradictory to earlier work showing whites to be generally less at risk of exposure to flooding (Bolin 2007; Dow 1992). However, the age distribution within white populations adds nuance to this finding. White New Yorkers in flooded census tracts were significantly more likely to be over 65 years old (z=66.7, 22.2 % of whites) than those in dry tracts (16.6 %). Additionally, older whites who were directly exposed to the storm surge were almost twice as likely (z=−65.7) to be living below the poverty line (21.9 %) than older whites living
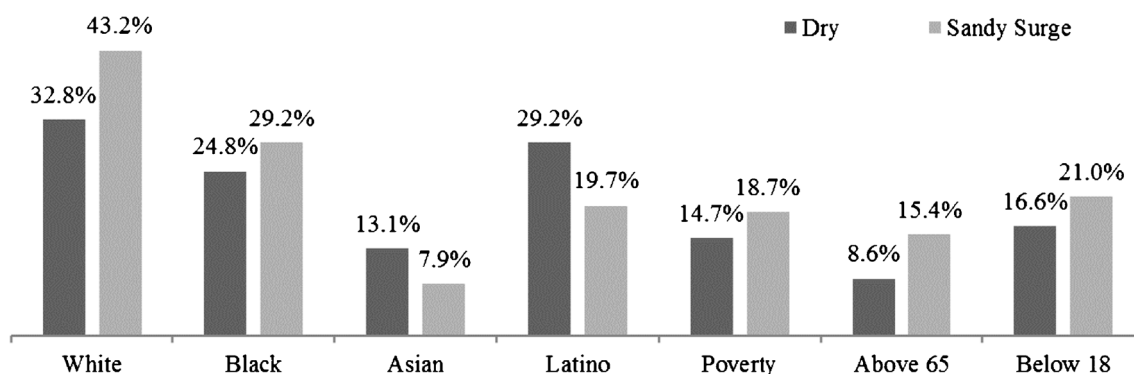
Fig. 3 Citywide demographic makeup by flood risk

Fig. 4 Storm surge and high-poverty areas
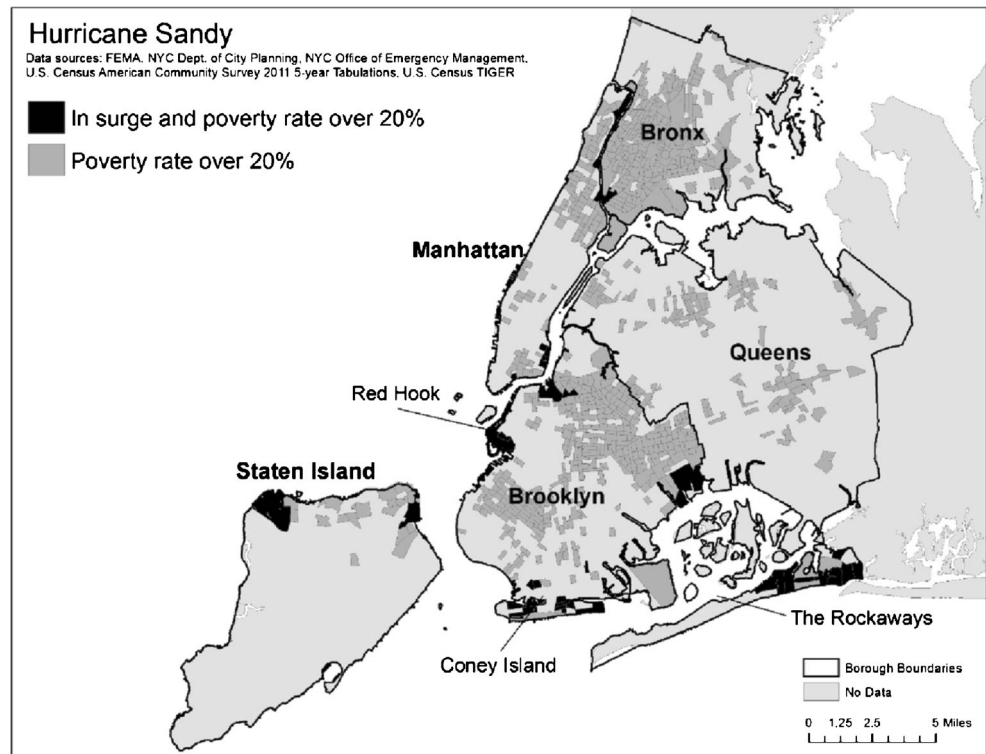
elsewhere in the city (11.4 %). The combined age and poverty differences across flooded and dry neighborhoods were not as dramatic for other racial or ethnic groups.

Flooded census tracts had larger black populations than dry tracts; and African Americans living in flooded areas were poorer. The storm surge also reached poorer Latinos. The higher representation of blacks and Latinos in flooded areas could be due to the extent of public housing in vulnerable neighborhoods such as Red Hook, Coney Island, and the Rockaways (Fig. 4). Over 400 public housing buildings with almost 80,000 residents lost electricity, elevators, heat, and hot water (Furman Center for Real Estate and Urban Policy2013; Lipton and Moss 2012). At the same time, there were more whites in flooded tracts, although they were older on average than whites in dry areas. Furthermore, older whites in flooded

areas were much poorer than those in dry tracts. More advantaged (i.e., younger and wealthier) whites were more likely to live in dry tracts. That the race and poverty status of the victims are unknown could reflect the fact that almost half were over 65 years old (Chavkin 2013).

Transit Access

Storm-damaged transportation infrastructure isolated many previously-connected communities. The MTA reopened some subway stations on November 1, 2012—only 4 days after they were closed in anticipation of the storm (Barr and Geller 2013). This was an important reestablishment of normalcy for the majority (55 %) of workers living in New York City who rely on public transportation to get to work (only 28.3 %

Fig. 5 Citywide, intra-race poverty rates by flood risk
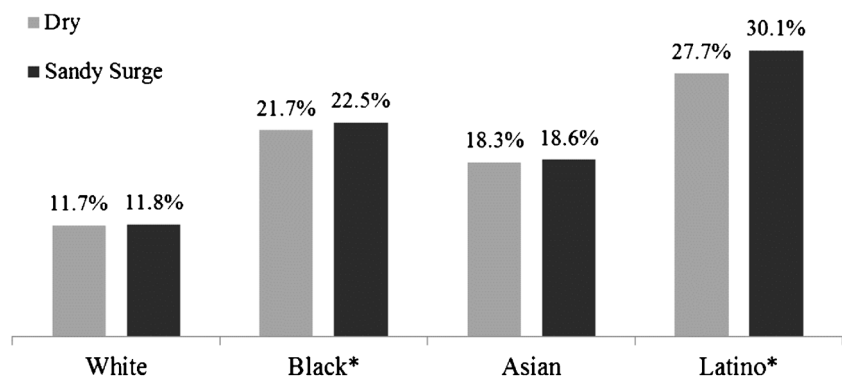
commute by car) (U.S. Census Bureau 2012b). In addition to working adults, 500,000 middle and high school students rely on subsidized subway rides to get to and from school (Schuerman 2010) (Fig. 6). Service on Staten Island, the most-flooded borough, remained closed. The lower third of Manhattan, central Brooklyn and Queens, as well as Brooklyn's southern coast were also without subway service. Only a few subway stations in the Bronx, the least flooded borough, were unable to reopen.

In all, 150 subway stations were closed due to flooding, downed trees, electrical cuts, and other problems. These stations served an average of 1,992,826 riders per weekday in 2011, accounting for around 38 % of weekday rides and just shy of the 2,151,877 average weekday ridership for the MTA bus system (Schuerman 2013). Thus, despite the restoration of most bus services, the limited subway access caused substantial disruption to many New Yorkers' social and economic lives. Reduced service resulted in abnormally high traffic gridlock. One survey of subway commuters found that commute times doubled and tripled for many, while 15 % of respondents were unable to work at all due to lost service (Kaufman *et al.* 2012).

My calculations based on ArcGIS's Network Analysis showed that for 40 % (836) of census tracts, home to 3,130, 183 people, the closest subway station after the storm was different than that before. For some communities, there was no subway stop accessible on November 1 without crossing water: 108 census tracts in Staten Island, 25 in Queens, two in the Bronx, and one in each of Manhattan and Brooklyn. These

137 tracts, with a population of over half a million people, were 58 % white and had a poverty rate of 14 %. Staten Island Railway service was eventually restored to full capacity on December 17 (Schuerman 2013), while services in the Rockaways were not restored until late May 2013 (Hinds 2013).

Excluding tracts that were left completely without transit services, citywide the average walking distance from the center of a census tract to the nearest subway station increased from 0.72 miles before the storm to 1.13 miles on November 1. The largest average increases were among census tracts in Queens (0.64 mile increase) and Manhattan (0.49 mile increase). In Brooklyn, the average walking distance to the nearest stop almost doubled, going from 0.49 miles to 0.85 miles (statistically significant at the 95 % confidence level for the three boroughs). Census tracts in the lightly-flooded Bronx did not see a statistically significant increase in the average distance to the nearest subway stop. Staten Island was excluded from this analysis because no subway stations were open there.

Those neighborhoods most severely affected by transit disruption were also quite different demographically from flooded areas. While black and white New Yorkers were more likely to live in census tracts that overlapped with the storm surge, average walking distance to the nearest stop increased by 0.37 miles in predominantly white areas (80 % non-Latino white or higher). Black neighborhoods, which were the farthest from subway stops before the storm (1.33 miles), saw a similarly-sized increase of 0.34 miles. Both Asian (1.19 miles)

Fig. 6 Post-Sandy subway access
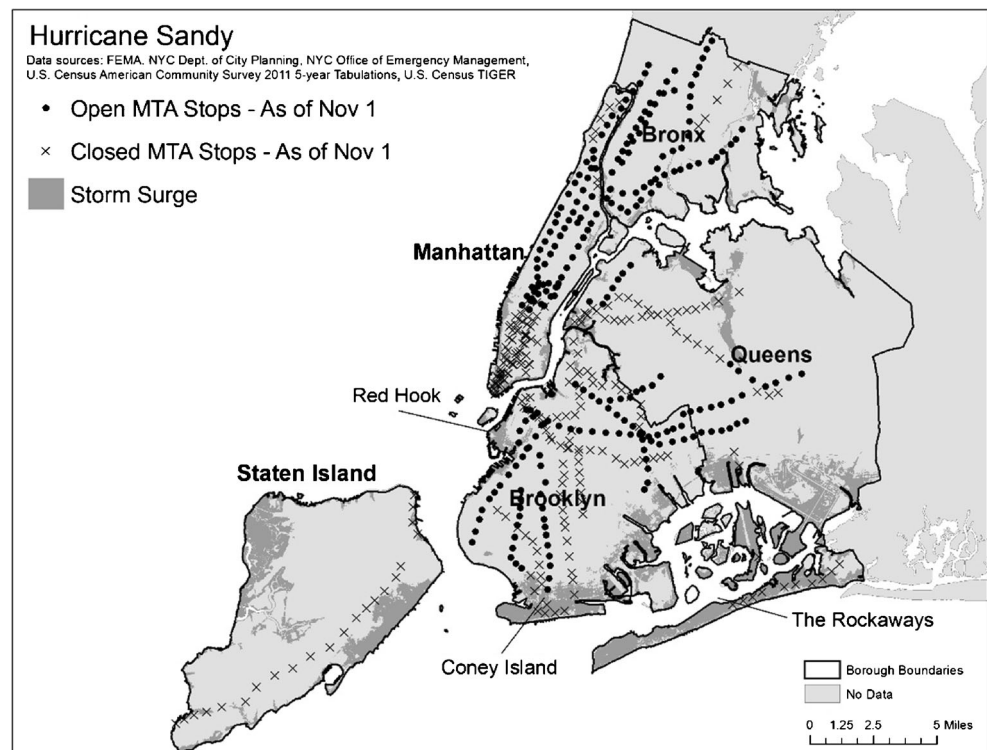
and Latino (0.59 mile) tracts were most dramatically affected by diminished subway service, largely because many were in Queens, which has relatively few subway lines compared to Brooklyn and Manhattan, and Manhattan's Lower East Side and Chinatown, both of which were left very far from subway service (Fig. 7) (all mean differences are statistically significant at the 95 % confidence level). While the most dramatic changes in access appeared to be among poor (poverty rate of 20 % or higher) Asian and Latino census tracts, there were not enough observations to determine whether these differences were statistically significant.

311: New Yorkers' Calls for Help

New Yorkers called the 311 system 37,998 times in the week after Hurricane Sandy, compared to 4,111 times the previous week. Of these, 14,313 were about downed or damaged trees. Another 11,840 were complaints and questions regarding building conditions, while sewer and electricity concerns comprised 1,622 and 571 of the calls, respectively. The dramatic increase was not surprising given the chaos caused by flooding, blackouts, and wind damage (Fig. 8). The values shown in Fig. 8 are the number of calls for a particular day divided by average number of calls of that type, for that particular day of the week, for that area, for all of 2012. A value less than 1, for example, indicates below-average call volume. The dashed line marks October 29, 2012, when Sandy came ashore, and corresponds with a decrease in call volume across flood risk, perhaps as people sheltered in preparation. Starting October 30, 2012, call volume rose dramatically across all neighborhoods. In flooded census tracts, call volume rose substantially and stayed relatively high through the end of December, with dips on Thanksgiving and Christmas. The number of calls from dry census tracts rose after the storm, but returned to around average by the end of November.

The number of building-related calls, which are indicators of numerous types of problems from lack of heat to dirty conditions, spiked after Sandy and remained high across all neighborhoods through December, though the increase in call volume was largest in flooded areas (Fig. 9). The pattern of electricity-related calls differs slightly. Normal call volume
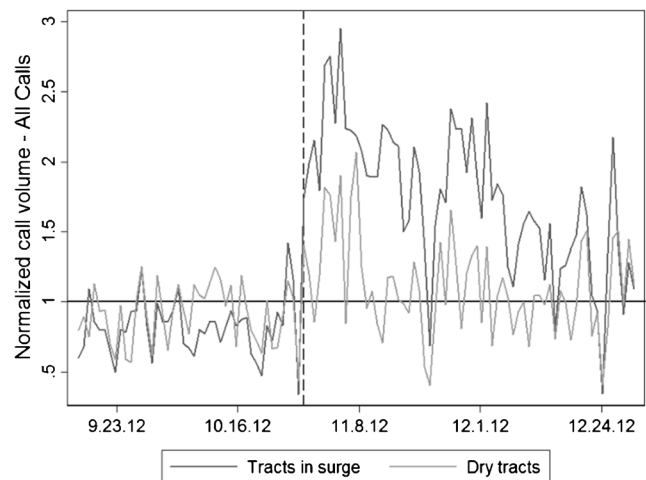

**Fig. 8** Citywide call volume by flood risk – All calls

rose dramatically in the hardest-hit neighborhoods and slowly returned to normal by mid-December. In dry census tracts, there was no noticeable difference in electricity-related call volume after the storm (Fig. 10). There was an enormous spike in the number of calls from flooded areas related to the sewer system right after the storm struck. Given the unprecedented flooding, it is unsurprising that the sewer systems were overwhelmed. Call volume was actually below average in dry areas following the storm (Fig. 11). Across all neighborhoods, call volume about dead or damaged trees spiked in the storm's immediate aftermath and returned to normal by December. The lack of a notable difference in trend or level across flood risk suggests damage to trees was more a result of wind than water (Fig. 12).

The disparities in building- and electricity-related call volume across flood risk showed combined vulnerabilities in New York City's low-lying coastal neighborhoods.. Greater signs of distress were expected for the hardest-hit neighborhoods, but what is remarkable is how long that distress persisted after the storm passed. Many communities had problems well into December 2012. Also worth noting is that as large as the disparities between flooded and dry areas appear, call volume may have actually been muted by power and cellular phone coverage loss in the hardest-hit neighborhoods.

Fig. 7 Average distance to nearest subway station (miles) by census tract demographic
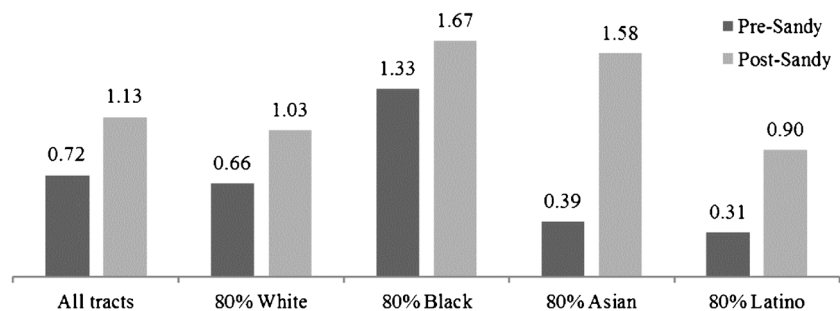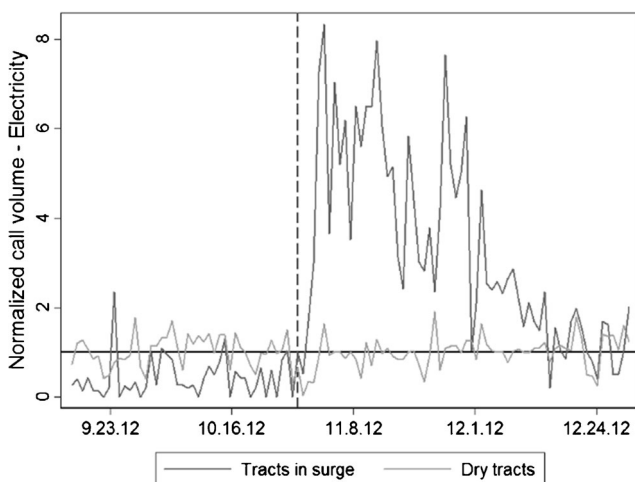

Note: of tracts that had access to transit after Hurricane Sandy. All within-group mean differences are statistically significant at the 95% confidence level.
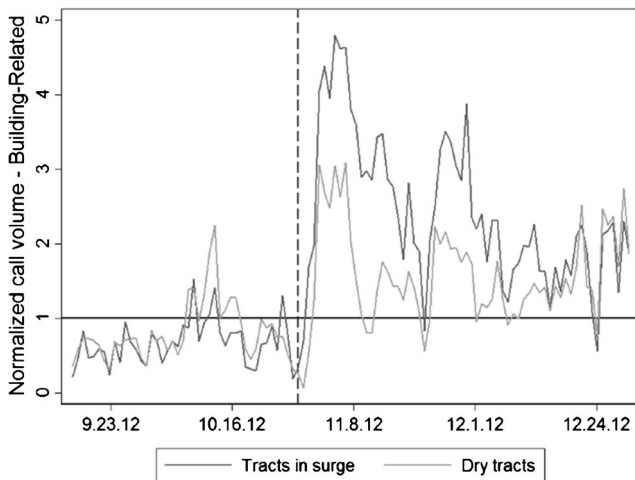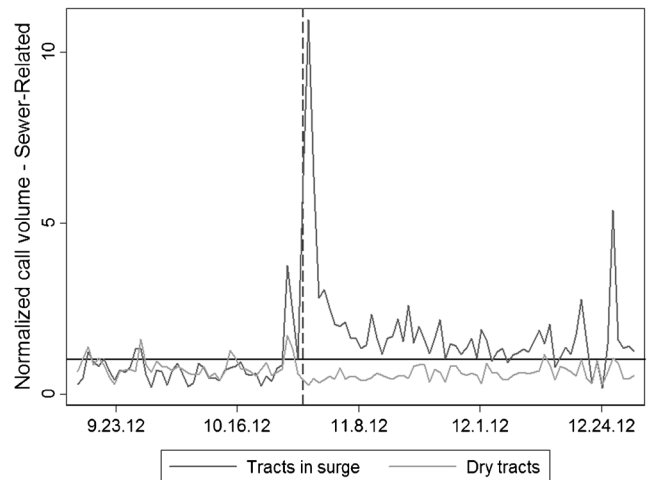
Fig. 9 Building-related call volume

Fig. 11 Sewer-related call volume

311 data allow for further analysis of across-group consequences of the storm. Because there were no predominantly (80 % or more) Asian or Latino census tracts within the storm surge, I was able to compare only black and white neighborhoods. There was an immediate spike in calls in black, flooded neighborhoods that was much higher than that in white, flooded neighborhoods (Fig. 13), although over time call volume declined in black, flooded areas as it picked up in white, flooded areas. Residents in white flooded neighborhoods continued to call 311 for assistance and information at a rate two-to-three times higher than the average rate and typically higher than that in black, flooded areas until Thanksgiving.

I also disaggregated calls by type in order to understand whether white and black flooded areas reported the same kinds of problems. Both electricity-related and building-related calls display a similar pattern: the normalized number of calls about electricity and building conditions increased for both white and black communities after the storm, though more dramatically in majority white areas (Figs. 14 and 15). Volume for both types of calls returned to around average by

early December. Calls about the sewer system (Fig. 16) followed a different trend: call volume in black, flooded neighborhoods rose to almost 25-times normal immediately after the flooding began, which was a much larger jump than that in white, flooded areas (around 10-times normal volume). There were not notable differences in the relative number of calls related to trees between black and white flooded tracts.

This analysis suggests black and white communities were differently-affected by flooding. In black communities, the sewer system presented immediate problems for residents, while white neighborhoods struggled more with electricity and building issues. This could be due to differences in housing stock across neighborhoods, where smaller, detached units were more common in white communities and perhaps more vulnerable to flood damage—as in Staten Island and the Rockaways. Conversely, public housing projects, which may be sturdier, were more common in heavily-flooded black areas. Again, it should be noted that call volume in the hardest-hit communities may have been impacted by power
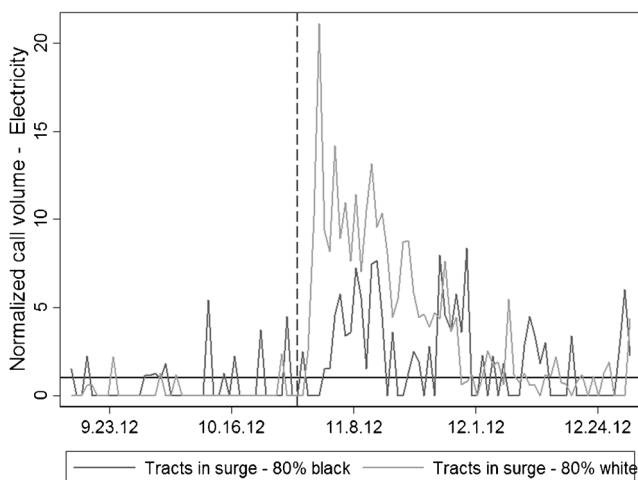

Fig. 10 Electricity-related call volume
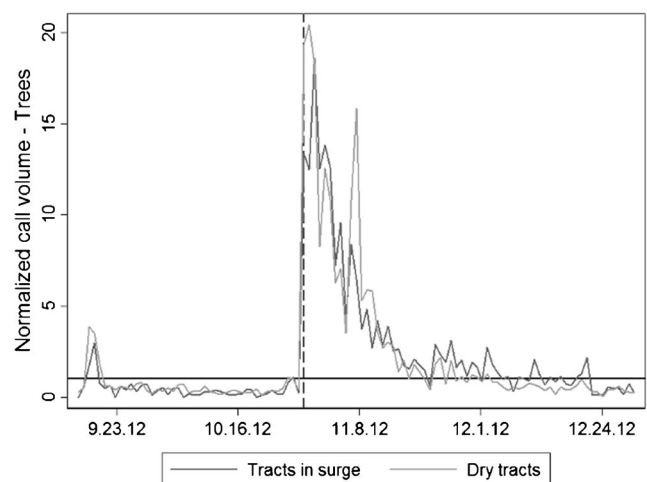
Fig. 12 Tree-related call volume
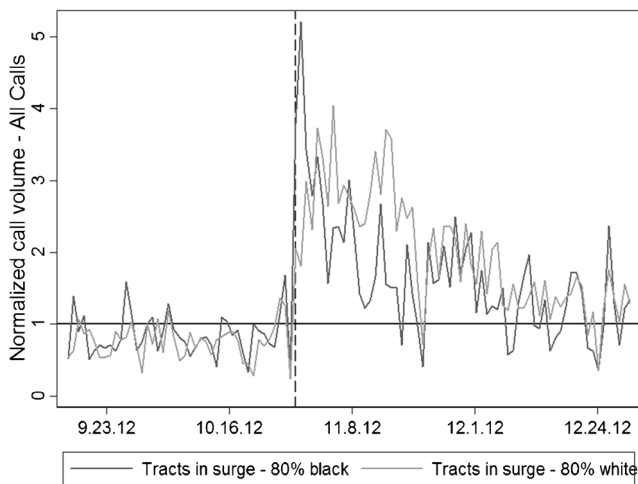
Fig. 13 White and black flooded tracts. All calls

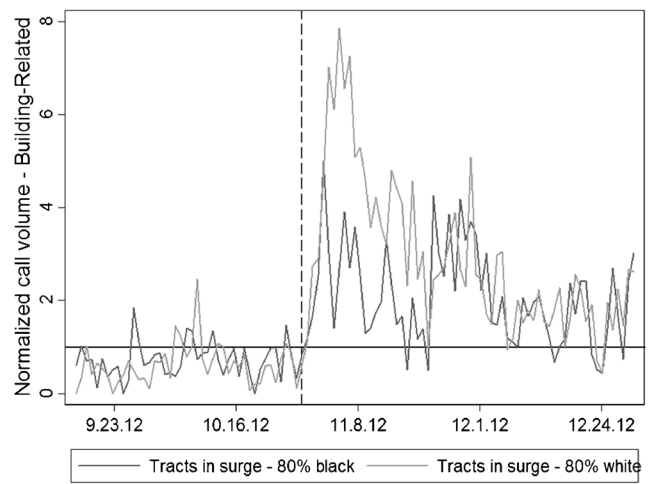**Fig. 15** White and black flooded census. Building-related calls

and cellular phone outages, so it is possible these data underestimate the distress in these communities.

Discussion

In light of climate change, cities across the globe will increasingly experience extreme weather conditions. Even if greenhouse gas emissions are restricted to limit the global temperature increase to two degrees, as proposed during the 2009 Copenhagen climate conference, we are likely to see dramatic environmental changes in the decades ahead (McKibben 2012; Parenti 2011). While the impact Hurricane Sandy had on New York City might not be directly comparable to its impact on a small, coastal community in New Jersey, it may be relevant to other major coastal cities around the world similarly characterized by segregation and inequality. The focus on New York City also benefitted from access to unique data sources such as public transit disruption and trends in 311 calls.

Three primary findings emerge from this analysis. First, vulnerability in the form of direct exposure to Hurricane Sandy's storm surge was shaped by the intersection of multiple social factors. The poverty rate in flooded areas was higher than that in dry tracts - nearly one of every three flooded census tracts had a poverty rate of 20 % or higher. Black New Yorkers and poor blacks in particular were more likely to live in flooded areas. While Latinos were less likely to live in flooded areas, those that did were generally poorer than Latinos in dry areas. Whites in flooded communities were more likely to be over 65 years old and higher rates of poverty compared to whites in areas that remained dry. While this finding is not in line with previous literature on race and vulnerability showing whites typically to be less exposed to flooding (Bolin 2007; Dow 1992), the fact that those who lived in exposed areas were older and poorer than those in dry areas is important both for understanding how social factors can combine to shape exposure to extreme weather and for policymakers looking to identify potential high-need communities in anticipation of a storm.

Fig. 14 White and black flooded tracts. Electricity-related calls
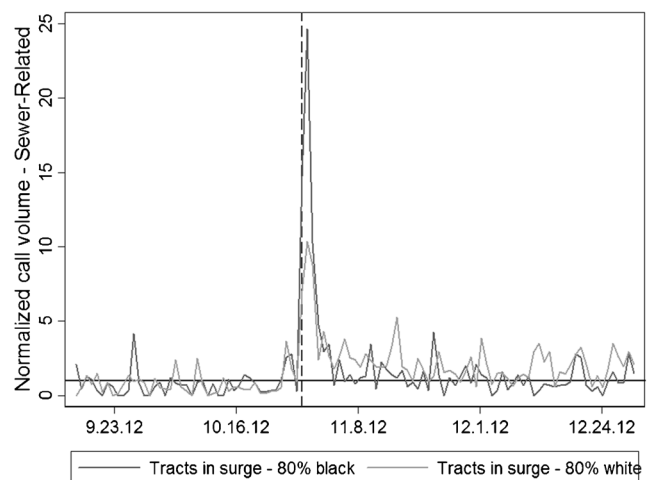
Fig. 16 White and black flooded census. Sewer-related calls

Second, analysis of transit disruption showed that the effects of a storm of Sandy's scale can have substantial consequences for communities located far from the flooding. Many communities were left isolated without access to schools, employment, social networks, or other crucial aspects of daily life. Furthermore, these consequences were not evenly spread across the city. Transit disruption in the storm's immediate aftermath had the greatest impact on Asian and Latino neighborhoods, particularly those in the borough of Queens, which had relatively poor transit access before the storm. The long term effects of climate change on transportation infrastructure have so far been understudied (Hunt and Watkiss 2011).

Third, data from the City of New York's 311 system suggest there was substantial variation in need across neighborhoods of different racial makeup and that flooded neighborhoods showed signs of distress for months after the storm. While scholars have previously argued that social factors can play a role in how exposure to the same event is experienced (Cutter *et al.* 2003; Fothergill and Peek 2004; Füssel 2007), these data provide a unique insight on a daily level of how flooded black and white neighborhoods were asking for different types of assistance from their local government. Residents in black, flooded areas reported a larger rise in sewer-related problems in the storm's wake, while calls from those in white, flooded areas tended to be about building and electricity concerns. This distinction, which may be related to variation in housing stock across neighborhood racial makeup, suggests a nuanced policy response was needed post-Sandy and will be needed in the case of future hurricanes. These data are a powerful tool which allows the City to respond in real time to the specific needs of a particular community.

The findings I present here differ from those presented in the City of New York's "Community Development Block Grant Disaster Recovery Partial Action Plan A" (New York City 2013). The City of New York's report found that flooded areas had larger white populations than dry areas, while black representation was around the same across flood risk. Also contradicting my research findings, the City characterized inundated neighborhoods as having lower levels of poverty than the rest of the city. These differences arise for two possible reasons: first, I used more recent data from the 2007–2011 American Community Survey (ACS), while the City's report relied on older data from the 2006–2010 ACS and the 2010 Decennial Census; second while I identified a census tract as flooded if its centroid was within the surge area, the City's report did so if a tract intersected with Sandy's flooding. My method is less likely to label areas as flooded by storm surge when they were not, which explains why the City reports that 10.3 % of New Yorkers lived in flooded areas (New York City 2013), compared to my estimate of 6.4 %. Census tracts in areas such as the Bronx, Staten Island, and Manhattan's West Side, which simply bordered a body of water, were largely unaffected by the flooding indicated by FEMA data, but were identified as flooded in the City's report.

New York City's 2014 Hazard Mitigation Plan (OEM 2014) also included a "Hurricane Sandy Retrospective Analysis." Under the heading "Impacts on Social Environment," OEM documented the fact that the elderly and the poor (perhaps a revision of their earlier finding) were more likely to live in neighborhoods flooded by the storm, but did not analyze race or ethnicity. The report focused on the substantial damage to the built environment, including transportation infrastructure. However, OEM did not explore differences in the extent of transit disruption across neighborhood racial characteristics. Similarly, the United States Geological Survey also explored the consequences of Hurricane Sandy to identify vulnerability to future storms, but focused on physical changes to the Atlantic Coast due to erosion rather than social factors (U.S. Geological Survey 2014).

The Rebuild by Design initiative, which is supported by President Obama's Hurricane Sandy Rebuilding Task Force, asked several research teams to assess the vulnerability of communities along the Eastern Seaboard incorporating social factors (Rebuild by Design 2014). Multiple teams identified New York City as vulnerable based on a combination of demographic characteristics and proximity to severe weather, which aligns with the claim by (Cutter *et al.* 2003) that Manhattan is the most socially vulnerable county in the United States. The Rebuild by Design findings, while different in focus than the research presented here, support the argument that the overlap between social disenfranchisement and environmental hazards should motivate policy aimed at mitigating the unequal effects of climate change and future research exploring the acute impacts of severe weather events, particularly in New York City.

Future research could leverage micro-level, longitudinal data to follow a heterogeneous sample of individuals exposed to flooding due to Hurricane Sandy. For example, researchers could identify students enrolled in schools flooded or otherwise damaged by the storm and compare changes in their academic performance over time to similar students in unaffected schools. In addition, they could track various indicators of recovery such as building permits or other commercial activity on the census tract-level and across different socioeconomic and demographic communities. Home Mortgage Disclosure Act (HMDA) data might offer additional insights into how different types of threatened communities are recovering. This dataset includes information on almost every mortgage application submitted to a lender by a prospective borrower. Mortgage application volume could be in a similar fashion to 311 call volume—but over a longer time period—to investigate whether homebuyers' decisions are affected by flood risk. If people, and particularly those with means, start to incorporate flood risk in their residential choices, larger racial

and socioeconomic disparities may appear as poorer residents are forced to live in increasingly precarious neighborhoods. This is essentially what has happened over generations in New Orleans, which has a longer history of severe flooding, where wealthier and white residents concentrated in higher-elevated neighborhoods (Fussell *et al.* 2010; Sharkey 2007).

In a more extreme case, if predictions about sea level rise and more regular, stronger storms are accurate, flood risk could lead to permanent displacement. In fact, New York Governor Andrew Cuomo has already decided to spend $400 million to buy land in Sandy-ravaged neighborhoods, which would never be built on again (Kaplan 2013).[3] This controversial policy will have significant implications beyond the large, immediate cost to government. If displaced people decide to relocate locally, New York City's already-taxed housing stock will need to absorb perhaps hundreds of thousands of people, many of whom have limited incomes. If those in areas prone to flooding leave New York City would lose tax revenue and voters.

It is also important to understand how local businesses may be responding to changes brought on due to climate change. If increased flood risk pushes people out of certain neighborhoods, businesses in those areas may suffer or move away. Even if residents do not immediately relocate, the fact that the damage to the city's subway system may not be repaired for years (Flegenheimer 2013) may reduce the commercial viability of investments in particularly hard-hit neighborhoods. Finally, while I focused primarily on race, poverty, and age, commonly understood as the most important markers of social vulnerability (Bolin 2007; Cutter *et al.* 2003), future research could analyze other dimensions of disadvantage, such as disability or immigration status.

Conclusions and Policy Recommendations

Although Superstorm Sandy caused unprecedented damage, New York City may actually have been quite fortunate. The storm had weakened substantially by the time it made landfall to the point that it no longer technically qualified as a hurricane (Santora 2013) and it brought substantially less rainfall than Hurricane Irene (Holthaus 2012) (Fig. 2). Nevertheless, almost a third of the entire city was within an OEM evacuation zone. Revised flood maps released by FEMA mark more areas further inland as at risk of flooding today (Buckley 2013), while seal level rise over the next few decades is expected to threaten hundreds of thousands more New Yorkers (Anderson 2013).

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[3] The fact that 1,800 units in Sandy-flooded areas were in foreclosure further complicates rebuilding efforts, because it may not be clear who is in charge of a foreclosed property (Furman Center for Real Estate and Urban Policy 2013).

The simple mapping of flood risk carries importance for individuals and families looking for a place to live as well as policymakers responsible for disaster mitigation, response, and adaptation. Additionally, analyzing the characteristics of the neighborhoods at risk in the context of increased weather intensity due to climate change is important for equity concerns and broader understanding of how place can be a stratifying phenomenon (Dreier *et al.* 2001; Logan and Molotch 1987)).

Vulnerable populations are often excluded from policy discussions regarding preparation for severe weather events such as Hurricane Sandy (Adger 2006; Eakin and Luers 2006; Davidson *et al.* 2007; Superstorm Reseach Lab 2013). The mixed evacuation compliance leading up to the storm (CBS New York 2012b) is perhaps indicative of a lack of trust between vulnerable groups and city government, which reinforces the need for communication and transparency. Community organizations could serve as links among stakeholders and powerful tools with which to involve politically marginalized people in preparation for future events. Previous work has shown that social infrastructure provided by community groups (including local businesses, churches, and friendship networks) can be just as important as physical infrastructure during crises and recovery (Davidson *et al.* 2007; Klinenberg 2002, 2013). New York City officials should not only leverage community organizations to spread information in preparation for extreme weather, but recognize that they can help coordinate rebuilding and communicate the needs of their constituency.

Cities present unique challenges for those responsible for creating evacuation plans, which typically reflect the suburban experience in which people are more likely to have private vehicles and the financial means to afford temporary housing (Cutter and Smith 2009). Evacuations of urban areas are further complicated by the higher concentrations of people (Cutter *et al.* 2004). One model FEMA employed in the wake of Hurricane Katrina was the temporary trailer as housing assistance. This method may not be suitable in a place like New York City, in which much larger buildings with many more residents may need to be evacuated. It may also be much more difficult to locate such short-term units within crowded cities. Additionally, previous research has found that the poor are more likely to rely on post-disaster housing assistance, since those with resources can afford to make their own arrangements (Bolin 1985; Bolin and Stanford 1991). The consequences of New York City's decision to house Sandy-displaced individuals in hotels and whether this strategy would or should be implemented again are still open questions. Developing new building codes intended to make housing storm resilient in the long term also risks making housing unaffordable for low income people. All of these factors reinforce the need to educate government responders regarding the diverse experiences of affected populations (Fothergill and Peek 2004).

Overlapping social and ecological vulnerabilities also mean efforts to alleviate poverty and inequality are relevant to disaster preparation, recovery, and resilience (Eakin and Luers 2006). While scholars are still working to understand the social aspects of vulnerability, there is consensus that environmental hazards are filtered through the social fabric of society (Adger 2006; Cutter 1996). Furthermore, widening inequality is increasingly being linked to climate change vulnerability (Eakin and Luers 2006) in a process Ross refers to as "eco-apartheid" (2011:17).

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