Public Health Implications of Hot Summer Days and Vulnerability Indexes in Massachusetts

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Abstract

Due to ever-increasing summer temperatures and a population with minimal technological adaptations to help them cope, extreme heat events will likely have a large impact on vulnerable populations in Massachusetts. As such, heat events are likely to impact the health of residents because they are related to a rise in all-cause hospital admissions and other health outcomes. We sought to clarify how Massachusetts may improve their extreme heat event response policies. To do so, we examined Massachusetts' current policies and best practices for extreme heat event response as well as the spatiotemporal weather and vulnerability patterns throughout the state. As a result, we found that varying the scale of response will be necessary based on the extent of different heat events. Additionally, the state ought to clarify who is in charge at the state and regional levels. By better addressing the needs of its populations during heat events, Massachusetts would likely prevent unnecessary hospital admissions and harm to its residents.

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Chapter 1: Introduction

With a projected 3 -5° Fahrenheit increase in temperature by 2100, the United States' population will likely be exposed to more extreme heat events (Davis, Knappenberger, Michaels, & Novicoff, 2003). For Massachusetts one group predicts that the annual temperatures will be similar to those currently experienced in Virginia in 25 years and South Carolina in 85 years (please see Image 1 of Appendix A for a pictorial representation of this) (Union of Concerned Scientists, 2006). This situation will likely be exacerbated because, like many northern states, limited access to technological adaptations, e.g. air conditioning, makes them highly vulnerable to heat-related adverse outcomes.

Background

In order to address this growing need throughout the commonwealth, we examine models of extreme heat events, temperature patterns, and vulnerable populations. We also examine current extreme heat event response best practices, and Massachusetts' policies. Generally speaking, there is little focus in the peer-reviewed literature on the role of the extreme heat events' locations and vulnerable populations and there is no exception to this in Massachusetts. This is innately problematic because the spatial relationship of the two may play a strong role between the people most influenced by the severe weather events and the events themselves.

Weather forecasts

When discussing weather modeling and the spatial relationship between weather and vulnerabilities, our analysis first examined methods of how to create downscaled temperature estimates. Hanigan et al. produced a study in 2006 comparing methods for the daily exposure estimates of weather on the health of populations. They found that the most appropriate method was to use weather data of stations within a 50-kilometer radius of the population centers (Hanigan, Hall, & Dear, 2006).

While Hanigan et al. determined that a model that worked in their situation, there are different ways of evaluating the efficacy of the various weather models. One way is to examine high-density measurement areas to test the validity of regional climate models (Beniston, et al., 2007; Hofstra, New, & McSweeney, 2009). One study by Stahl et al. compared the interpolation of maximum and minimum daily temperatures using 12 weighted-average and regression-based models in British Columbia, Canada. In this study elevation played a huge role in the models' efficacy because the region is highly mountainous; the models' accuracy depended less on the weighting and more on the elevation differences. All models performed better during years with the greatest station density; in the Stahl et al. study, the simplest inverse distance weighting models that excluded elevation during years of high station density performed similarly to the best models they tested (Stahl, Moore, Floyer, Asplin, & McKendry, 2006). On a global scale, a different group of researchers used a kriging method that combined station data with satellite temperature estimates. They validated these estimates by randomly selecting one station for every 50 square kilometer pixel and compared that to the interpolation of just the station data. They found that including the satellite data was most important at higher elevations; the difference between the standard errors and R-squared values at lower elevations was not as extreme (Kilibarda, et al., 2014). As both of these examples describe, extremely high elevations generally make interpolation less precise.

Additionally weather models that are not sensitive to temporal differences can introduce error. As Wilks and Wilby noted in their 1999 article reviewing the development of stochastic weather models, seasonal and inter-annual weather variability is often not displayed in the conventional weather models (Wilks & Wilby, 1999). For instance, Wilby's 2002 article examining the seasonal variation in spatial relationships found that even for different measurements taken in a small area across the British Isles, there can be great spatial variation among the correlation coefficients, i.e. areas with strong weather similarities could vary depending on the season (Wilby, Conway, & Jones, 2002). Therefore it seems reasonable to assume a model that has sufficient station density, is temporally sensitive and is for an area of limited elevation variability should provide reasonable local temperature estimates.

Vulnerabilities and Hospitalizations

The spatial distribution of vulnerabilities also plays a large role in how heat events will impact local populations. Early in the 20th century there was a belief that the stress of higher income professions would likely have an increased impact on negative health outcomes. However, research that emerged in the latter half of the century began emphasizing the role that poor socio-economics played on health. The longitudinal Whitehall Study of 17,350 British Civil Service servants was one of the first studies to determine the impact of low socio-economic status on negative health outcomes. In that study, the relative risk of mortality significantly increased for those workers as their employment grade decreased (Marmot, Shipley, & Rose, 1984). More recent articles have found statistically significant relationships between environmental and socio-economic factors to hospital admission rates (Arbaje, Wolff, Yu, Powe, Anderson, & Boult, 2008; Boult, Dowd, McCaffrey, Boult, Hernandex, & Krulewitsh, 1993; Burns & Nichols, 2003).

One review of studies examining neighborhood level factors and their associations with health outcomes found that despite the variety in research methods used in different studies, there was consistent evidence that neighborhood factors are related to the health of the inhabitants (Pickett & Pearl, 2001). However, when examining readmission rates another review of 7,843 citations found that neighborhood factors including social support, access to care and substance abuse were not widely studied (Kansagara, et al., 2011). In relation to this thesis another study examining the a heat vulnerability index based on neighborhood-level factors in metropolitan statistical areas across the US found a significant relationship between the neighborhood level index and all-cause hospital admissions during heat events (Reid, et al., 2009).

Previous work:

As noted above, initial work to characterize vulnerable populations in Massachusetts was conducted as part of the Environmental Public Health Tracking program's analysis of populations vulnerable to extreme heat conditions. Through that collaboration, Reid et al.'s

2009 Heat Vulnerability Index (HVI) was evaluated to determine whether areas with high HVIs experienced higher rates of morbidity and mortality on abnormally hot days (Reid, et al., 2012). For Massachusetts' metropolitan statistical areas, the HVI was found to be associated with morbidity and mortality on both abnormally hot days and normal days. Thus, the HVI was found to be a good indicator of overall health vulnerability.

Following the Reid et al. article, another unpublished study in Massachusetts found associations between the towns' average interpolated daily maximum temperature and rates of emergency department heat-related visits. They used the hospitalization database provided by the Massachusetts Department of Public Health and the 2002 daily maximum temperature data from the National Climate Data Center's stations to identify the communities in the state with the greatest likelihood of having an increase in hospitalizations by 2030. One outcome of that study was the state's emergency department heat-related visits' rate and the daily average; a graph of this is displayed in Image 2 of Appendix A. This image provides a visual description of the statistically significant relationship between the maximum daily temperature and the emergency department heat-related visits.

Study goals

For this thesis, we sought to determine if there are better ways to match Massachusetts' public health policies during extreme heat event responses with the state's spatiotemporal patterns heat and vulnerability. This study aims to combine the spatiotemporal variability of maximum daily temperatures and the neighborhood vulnerability factors, while accounting for best practices and what is feasible given existing resources.

Overview

In Chapter 2, we began by doing a literature review of extreme heat event best practices both domestically and internationally. We then, in Chapter 3, examined the current policies in Massachusetts in order to gain a fuller understanding of the way in which extreme heat events are handled. Ultimately to more closely examine the spatial relationships that may exist between the extreme heat events and the community vulnerabilities, we performed 3 steps described in Chapter 4:

1) We examined the weather in 2012 based on our interpolations.
2) We inspected the census-tract level vulnerabilities across the state
3) We combined the first two steps in order to have a stronger sense of the overarching spatiotemporal trends.

Lastly, combining all of the above information in Chapter 5 we were able to establish actionable steps that different players in Massachusetts could take to improve the extreme heat event response.

Chapter 2: Extreme Heat-Event Response Best Practices

While there is limited consensus around the ideal assemblage of best practices for emergency response and preventative strategies to heat-related emergencies, some guides may be used to inform the optimal response for Massachusetts's communities. One such guide is Bernard and McGeehin's 2004 article in the American Journal of Public health. The article outlines six primary strategies for an effective municipal heat response system. These six components are outlined below:

(1) identification of a lead agency and participating organizations;
(2) use of a consistent, standardized warning system activated and deactivated according to weather conditions;
(3) use of communication and public education;
(4) implementation of response activities targeting high-risk populations;
(5) collection and evaluation of information; and
(6) revision of the plan (Bernard & McGeehin, 2004)

In order to understand how these overarching principles apply to actual policies, we examined three extreme-heat response guidelines to understand the current state of practice: the Environmental Protection Agency's (EPA) Extreme Heat Events guidelines, the World Health Organization's (WHO) Heat Health Action Plans Guidance and the Center for Disease Control's (CDC) extreme heat website.

EPA's Extreme Heat Events Guidelines

The EPA developed the Extreme Heat Events (EHE) guidelines in 2006, in order to provide guidance and sufficient background on the risks and impacts of EHEs to local public health officials. By considering the growing frequency and potential severity of EHEs, the guide outlines the argument that with meteorological predictions there is sufficient lead time to act, there are specific high-risk populations that are already known to be more vulnerable to EHEs and there is broad consensus around the type of action that ought to be taken in emergency response. They draw on low-cost interventions that can be implemented at a local level in order to reduce the heat-related health impacts (EPA, 2006).

WHO's Heat Health Action Plans Guidance

The World Health Organization developed the Heat Health Action Plans Guidance in 2008. Based in the physiological affect on the human body and the public health literature related to the health effects of high heat exposures, their model for addressing community-level heat response focuses on using existing emergency response infrastructure, mitigation strategies, cross-sectorial approaches, and effective communication. The guideline suggests interventions at the regional or country-level. They also emphasize the importance of monitoring the systems' success at reducing heat-related adverse health outcomes (Matthies, Bickler, Marín, & Hales, 2008).

CDC's Extreme Heat Website

The Center for Disease Control's (CDC) website on extreme heat is targeted towards individuals seeking information about ways to protect themselves. Their website may be useful for health departments to reference when giving people information about extreme heat events (CDC, 2009). The CDC also produced a toolkit for communicating issues around climate change, extreme heat and health. Connected to the larger environmental public health tracking network, which tracks environmental health conditions all over the country, the focus of the toolkit is simply to explain how local health departments can communicate the risks of heat to their communities (CDC, 2013).

Comparison of Best Practices

Table 1 in Appendix B displays the distinctions among the three guidelines. Beginning with individual-level interventions, it is clear that both the CDC and WHO are promoting advice to community members directly by suggesting behavioral changes, accessing cooler environments and installing air conditioners within individual homes. The WHO guide further emphasizes built-environment related interventions including passive cooling technologies, insulation and external shading. The two US-specific guidelines fail to include anything related to building modifications. This may be partly due to the scope of the guidelines and the belief that such building-modification related recommendations are within other agencies' jurisdictions. The trend of the US-produced guidelines missing more preventative strategies is evident among the other long-term policy recommendations; the WHO's guideline emphasizes specific policy changes to reduce impacts of climate change including building regulations and land-use changes while the EPA and CDC's guides do not specifically describe mitigation strategies.

Among the short-term event-responsive recommendations, the US guidelines become more dynamic. For example, the EPA suggests having predictive capabilities to determine an extreme heat event up to 5 days prior to the event. The EPA and WHO also recommend some risk-assessment steps including an estimate of the heat-event's health impact as well as gathering information on high-risk populations and locations of large concentrations of high-risk people. All three guides recommend coordination of public broadcasts about the heat event and interventions. The CDC and the WHO further recognize the role that healthcare professionals can play in notifying at-risk populations by suggesting outreach specific to healthcare providers. When it comes to other types of emergency response, the EPA's recommendations are more thorough than the other two guides. The EPA's guide includes restricting the utility turn-offs, opening informational phone lines, and rescheduling large outdoor gatherings. Both the EPA and the WHO describe the need to open cooling centers, organize extra staffers, and evaluate the ongoing condition for high-risk individuals.

There is consensus around communicating to the general population about the effects and risks of heat waves. While some of the guides focus on short-term emergency response, other guidelines focus on the longer-term policy decisions that could be made in order to reduce the vulnerability to heat. Additionally, based on the focus of the organizations, the scale for the recommended action is strikingly different among these guidelines. The WHO recommends a regional or even countrywide scale, the EPA focuses on the municipality's role and the CDC emphasizes the individual's role. For the purposes of this paper, drawing from each of these scales may be valuable in order to address the needs of Massachusetts's communities.

Chapter 3: Massachusetts Extreme Heat-Event Response

Just as the WHO and EPA guides describe, the Human Health and Welfare Chapter of the Executive Office of Energy and Environmental Affairs (EOEEA) 2011 Climate Change Adaptation Report for Massachusetts identified the need to better understand population characteristics and conditions that could contribute to disproportionate risk and obstacles to resiliency (Executive Office of Energy and Environmental Affairs, 2011). This is a necessary step in order to better understand the needed resources for an emergency response to heat events. However, a 2014 survey performed by the Massachusetts Department of Public Health's Bureau of Environmental Health analyzing the preparation of local health departments found that there was a need for better information to characterize vulnerable populations at the community level because the local health departments felt ill equipped to handle climate change events (Massachusetts Department of Public Health, Bureau of Environmental Health, 2014). This poor preparation at the municipality level appears to be mirrored statewide with the Massachusetts Emergency Management Agency (MEMA) providing the State Hazard Mitigation Plan, which is the most comprehensive plan for the Commonwealth.

MEMA Mission

MEMA is the state agency responsible for ensuring that Massachusetts will be able to respond to and recover from disasters and emergencies. It consists of planners, operations, support personnel and communication specialists who build partnerships with governments and private entities at the local, state and federal levels (Commonwealth of Massachusetts, 2014). When it comes to heat-related responses, MEMA's response is relatively limited. MEMA's informational webpage concerning extreme-heat events has minimal location specific information. It primarily focuses on individual level interventions and risk factors for heat-related adverse health outcomes (Commonwealth of Massachusetts, 2014).

When it comes to the statewide plan, MEMA will declare a heat advisory if it is first issued by the National Weather Service's (NWS) Taunton Forecast Office. The NWS issues heat advisories when the heat index anywhere in the state exceeds 100° Fahrenheit for longer than 3 hours. The NWS also extends an excessive heat warning if heat indices in the Commonwealth are above 105° for longer than 2 hours. Additionally MEMA, based on the NWS definition, defines a heat wave as a three consecutive day period with temperatures above 90° Fahrenheit. While MEMA's 2013 State Hazard Mitigation Plan explicitly describes actions for specific players during many other weather emergencies, it fails to clearly identify the key players responding to heat events. They describe how the several-days' notice provided by meteorologists allows "an opportunity for public health and other officials to notify vulnerable populations." On the other hand, the State Hazard Mitigation Plan does provide broad guidelines for excessive heat warnings when heat events are predicted within the next 36 hours but MEMA lacks a specific explanation of how they will do this (Commonwealth of Massachusetts, 2013). The 36 hours in the State Hazard Mitigation Plan is relatively lenient because the EPA guidelines suggest 5 days. However, the 5-day weather forecast is less reliable than the 2-day forecast that would provide the 36-hour prediction. Over the past 20 years, the weather forecasts have improved; a 5-day weather forecast today is as reliable as a 2-day weather forecast 20 years ago (Time and Date AS , 2015). Extending the lead-time, may provide more forewarning for ramping up the response.

Despite a limited comprehensive, statewide heat-event response, there are some resources that are available for all Massachusetts' residents. An information hub is provided by a nonprofit organization called Community Resources Information, Inc. MassResources.org is their website where residents can visit and learn more about Massachusetts heat wave resources (Community Resources Information, Inc., 2014). That website provides links to local governments' announcement pages regarding their heat wave response as well as more information on statewide programs including the utility shutoff protection program (which was also suggested by the aforementioned EPA guide). Nevertheless, as a result of the limited statewide assistance, the current plans include municipalities being the primary players when respond to extreme heat events.

Massachusetts' Municipality Policies

Like many states in the US, Massachusetts's municipalities are responsible for much of the emergency response to heat events. This is unsurprising because other guidelines for communicating the climate change health risks emphasize that communication occurs best when it is local and performed in a context-appropriate manner (Maibac, Nisbet, & Weathers, 2011; APHA, 2011). However, communities receive varying degrees of support for vulnerable populations during extreme-heat events. Outlined below are 3 of the largest municipalities' response measures for extreme heat events.

Boston's Heat Alert Plan

Boston has a 'Heat Alert Plan' that is phased in from the city's emergency response department. The first phase, a heat advisory, is activated when the temperature is above 86° Fahrenheit and 68% humidity for two consecutive days. In a heat advisory the mayor is to contact the media and the city to send out a recorded public service phone call to anyone above the age of 65. This call explains the dangers of heat. The second phase of the plan, a heat alert, includes extending swimming pool hours, advisories at home care agencies to set up phone trees, and opening cooling centers (places where people can sit in air-conditioned spaces and drink cooled water). The third and most extreme phase is the heat emergency phase. Most of the actions are the same as the second phase except the heads of various municipal departments meet to discuss future response (Adler, Harris, Krey, Plocinski, & Rebecchi, 2010). Like Boston, some towns in Massachusetts have cooling centers but smaller towns often have partial, less comprehensive approaches due to limited resources.

Springfield's Cooling Centers

Springfield's approach strictly focuses on cooling centers and individual-level interventions. For example during a heat wave in 2011, the city of Springfield opened 6 cooling centers throughout the town. This was announced through a press release out of the mayor's office and posted to the town's website. The press release also described steps that individuals could take to protect themselves from heat-related adverse health outcomes as well as how to protect pets (The City of Springfield, Massachusetts, 2011).

Worchester Spray Parks and Cooling Centers

The city of Worchester has a multi-pronged approach to heat wave response as they extend their swimming pool operating hours and open cooling centers. One example of this is on March of 2014, the city opened the 5 cooling centers and extended swimming pool and spray park hours closing them at 8pm. They also provided transportation to the centers. This was announced through a media source, NBCuniversal as well as on the city's website (NBCUniversal Media, LLC, 2014).

Implications of Local Heat-Event Response

The limited transparency for statewide action to mitigate extreme-heat events is not necessarily a harmful situation for all residents in the Commonwealth but it can have negative implications for the residents of municipalities that lack comprehensive extreme-heat response plans. Additionally, if we return to the overarching six strategies that Bernard and Mcgeehin laid out in 2004, we see that statewide there is no one lead agency despite many participating organizations. For each municipality, there do seem to be consistent warning systems; however, across municipalities, the warning systems appear to vary. Furthermore, there are dissimilar activities in all municipalities when it comes to targeting high-risk populations. These discrepancies between municipalities further the need to investigate the spatial distribution of vulnerabilities and heat throughout the Commonwealth in order to determine the optimal scale at which heat-events should be addressed.

Chapter 4: Scale of Hot Days and Vulnerability Indexes in Massachusetts

> *Vulnerability is the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place, risk and mitigation with the social profile of communities* (Cutter, 1996).

Using the EPA's definition of an exposure assessment, there are two major components: the magnitude and location of the hazard as well as the types of human populations that are likely to be affected (EPA, 1992). These definitions provided the basis for our spatial analysis of vulnerability and heat exposure throughout Massachusetts.

Exposure Mechanism

Hot ambient air temperature affects the human body by increasing the body's temperature, which promotes an increase of superficial circulation and an elevated heart rate to cool the inside of the body. The cooling is continued by an increase in perspiration, which simultaneously decreases the amount of fluid for internal organs (Basu & Samet, 2002). The most common heat-related cause of death is the heatstroke, when a person's body temperature exceeds 105° Fahrenheit (McGeeehin & Mirabelli, 2001). Heat is also known to contribute to other causes of death including ischemic heart disease, stroke, diabetes, and respiratory disease. Capturing this relationship can be challenging because the broad classification of circulatory or respiratory-related outcomes are often not recorded as being heat related (Davis, Knappenberger, Novicoff, & Michaels, 2003)

Vulnerabilities

Certain populations experience the adverse effects of heat waves and hot ambient air temperatures more intensely than others. During the 1995 and 1999 heat waves in Chicago and France's 2003 heat wave, heat-related fatalities were highest among those who lived alone and did not leave the house on a daily basis (Klinenberg, 2003; Poumad`ere, Mays, Le Mer, & Blong, 2005). Socially isolated situations are naturally exacerbated by other vulnerabilities such as diabetes, obesity, and age; e.g. people living alone that are 65 and above (Reid, et al., 2009). Populations with limited access to technological adaptations, like air conditioning, are particularly vulnerable to hot days (Executive Office of Energy and Environmental Affairs, 2011). With historically cool summer temperatures, communities in Massachusetts often have limited access to air conditioning and other technological adaptations to mitigate the risk of hot weather. Below are explanations of each vulnerability category.

Age-Related Outcomes

The youngest and oldest of a population are more at risk to adverse health outcomes than others. Young people are at an increased risk to toxins due to their nearness to the ground, distinctive dietary habits, and their hand-to-mouth behavior (Landrigan, et al., 1999). This is critical because in the changing climate Massachusetts is likely to experience new pests and plants. Additionally, children are likely to be impacted by an increased use of pesticides due to new plant pests and diseases as well as increased particulate matter from air pollution that will affect them while exercising or spending time outdoors. (Executive Office of Energy and Environmental Affairs, 2011). On the other end of the spectrum, older populations face increased mortality during hot weather (Hulme, et al., 2002). Additionally, due to the fact that older people are more susceptible to malnutrition and other dietary diseases, the increased number of droughts and floods associated with climate change will likely impact older people through water quality and food security (Executive Office of Energy and Environmental Affairs, 2011; Schmidhuber & Tubiello, 2007).

Isolated Populations

During the 1995 and 1999 heat waves in Chicago, heat-related fatalities were highest among those who lived alone and did not leave the house on a daily basis (Executive Office of Energy and Environmental Affairs, 2011). This was also seen during France's 2003 heat wave, when 92% of the victims lived alone. One in four of the victims had no family, friends, or other social interactions (Poumad`ere, Mays, Le Mer, & Blong, 2005).

Socio-Economic Indicators

Race

Stemming from a long history of inequality, minority populations are still more vulnerable to adverse health outcomes than non-minority populations. Additionally, minority populations are more likely to live in communities highly vulnerable to climate change effects and other risks (English & Richardson, 2013). This is further shown by the broad adverse health outcomes associated with minority populations. For example in the United States since the 1960's, the overall mortality rate and infant mortality rate among black people have been twice as high as those among the white population (Woolf & Braveman, 2011).

Poverty

People without access, whether due to finances or to location, to quality preventative healthcare can be most susceptible to a decrease in air quality and other health risks. These same people also often face limited access to nutritious foods and are likely to be most affected by impacts on food systems and an increased use of pesticides due to new plant pests and diseases (Executive Office of Energy and Environmental Affairs, 2011). Not surprisingly, poverty was found to be directly related to increased mortality rates during heat waves (Curriero, Heiner, Samet, Zeger, Strug, & Petz, 2002; Kima & Joh, 2006; Naughton, et al., 2002).

High School Education

With limited material resources, social capital and health related behaviors, people with lower education levels generally have poorer health outcomes (e.g. higher rates of infectious disease and lower life expectancy) and are often considered to be more vulnerable than people with higher education (Center for Disease Control and Prevention, 2013). This held true in 11 US cities where communities with low percentages of population with high school diplomas were more susceptible to higher heat-related mortality rates (Curriero, Heiner, Samet, Zeger, Strug, & Petz, 2002).

Green Space

Green space is land covered by plant life. As such, in urban areas with minimal green space and high amounts of impervious surfaces the urban heat island effect is more prevalent when compared to surrounding greener locations (Gill, Handley, Ennos, & Pauleit , 2007). Urban heat islands have been found to increase energy consumption, air pollution, ambient air temperature and decrease water quality. For this study, we did not include air quality but if air quality were included green space would be one way of mitigating the effects of poor air quality. The urban heat island directly impacts residents during heat waves. Independently, impervious surfaces are also known to increase flood risk (United States Environmental Protection Agency, 2013). One way to mitigate this issue is through more green space. Vegetated surfaces can provide a cooler microclimate for evaporative cooling, shade, and rainwater interception, storage and infiltration (Gill, Handley, Ennos, & Pauleit , 2007).

Pre-Existing Conditions

People with existing respiratory diseases, particularly young children, are at increased risk due to high temperatures, elevated levels of ozone and the presence of particulate matter. Increased pollen production can likely aggravate existing allergies and respiratory diseases (Executive Office of Energy and Environmental Affairs, 2011). 70% of the victims in Paris's 2003 heat wave had some pre-existing health condition (Poumad`ere, Mays, Le Mer, & Blong, 2005). People living with diabetes are more vulnerable due to their water and food sensitivities. Food and water system issues related to heat waves and other emergencies will likely impact people living with diabetes (Executive Office of Energy and Environmental Affairs, 2011).

Objective

We investigated the spatial distribution of historical daily maximum temperatures, a population-level vulnerability index and a combination of the two in order to determine the scale at which would be appropriate for efficient emergency response levels.

Methods

We chose to limit the scope of our analysis to the months of April through September during 2012. This limited number of months is common practice in the literature and allowed for a focus on the hottest months in Massachusetts. This study's analysis consisted of three major parts:

1. Maximum Temperature Exposure or Weather,
2. Vulnerability Indices and
3. Combination of the above.

Throughout the analysis process, we used descriptive statistics and maps in order to determine the spatial exposures of more vulnerable and exposed populations; however, for each of these analyses, we performed different operations.

Weather

Initially we extracted station-level data from the National Climate Data Center for every day within 2012's April-September months. We only used daily maximum temperature data because that is a standard in the literature even though we understand there are many other risk factors associated with and benefits for using air quality, wind and humidity data in conjunction with the temperature data. For the year 2012, there were 68 stations throughout the state that provided maximum daily temperatures. For each of the days within the scope of this study, we created raster images using an inverse distance weighting interpolation. This created 500-meter grid cells with the estimated temperature for that day. Then using a *'zonal statistics to table'* tool, we were able to find the average temperature within each of Massachusetts' census tracts. Using this output, we were able to determine which census tracts were estimated to have temperatures above 86 ° Fahrenheit.

To define a heat wave, we used Boston's current policies as well as Robinson's definition of a heat wave,

> *an extended period of unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population* (Robinson, 2000).

The percent humidity was not captured for each of the stations and therefore was excluded from our analysis. We defined a heat wave as three days with temperatures above 86° for any location in Massachusetts. A two-day or longer break in the heat wave would signify the end of one heat wave and the beginning of another. This method created four heat wave groups.

Vulnerability

We mapped vulnerabilities using 2012 American Community Survey estimates of the percent of population in the identified vulnerability categories:

- Percent Poverty
- Percent without High School
- Percent Not White
- Percent Living Alone
- Percent 65 and Above Living Alone
- Percent 65 and Above
- Percent Non Green-Space

We joined these different census tract tables to a Tiger shapefile in order to display it spatially and mapped the quartiles using choropleth maps. Then, to determine the prevalence of spatial clustering, we used a Moran's I with a spatial weights matrix to perform a local spatial autocorrelation test. This allowed us to see the extent to which there was grouping among the different variables.

Lastly, in order to build off of the existing literature and to combine these varied vulnerabilities, we built index variables based on the Reid et al. 2009 paper that examined heat vulnerability indices throughout the US. We examined two of these indices visually using choropleth maps.

Combination

Using the heat-wave groups we found in the weather portion of the analysis, we were able to look at the aggregated indices and vulnerability categories. For each census tract with days above 86° Fahrenheit among the heat wave groups, we found the estimated total population that was vulnerable within each of the vulnerability categories. For example, among census tracts with a population of 1,000 people and 86% were above the age of 65 years, we assumed that 860 people would be vulnerable as long as the temperature for one day during that heat wave group was above 86° Fahrenheit. We could not sum these amounts because the vulnerable groups were never mutually exclusive. For instance, some of the people who are living below poverty are likely to also be above the age of 65. Additionally, summing these populations is further complicated because in census tracts with multiple days above 86° Fahrenheit, the same number of people would be vulnerable for many days. As a result, we only included the populations once.

We examined how the vulnerability index could be used to determine the degree to which a population was at risk. In order to do this well, we created a dot density map with the colors representing different groups of the index. The density of the dots were determined by the total population of the tract, each dot representing 500 people, and the dot's color represented the vulnerability index for that population.

Findings

Weather

In Appendix C, Table 1 describes the within station variation over the entire study period as well as the temperature variation throughout Massachusetts. The within station variation (with an average of 48°) is much higher than the daily variation between stations (with an average of 18°). This variability emphasizes the importance of both the spatial and the temporal trends while highlighting time's role in the exposure to heat waves.

Figure 1 shows the average of the daily maximum temperature for each station over the study period. This map indicates that on average over the spring and summer study period, there are substantial differences across Massachusetts in average of the daily highs.[1] The coolest one-

[1] For instance, this map captures an unexpectedly cool average daily maximum station temperature from one station near Worchester at the Worchester Regional Airport. One would assume that due to the urban heat island effect and that it is inland (not experiencing the ocean breeze), it would be warmer than many of the other stations surrounding it but this is not the case. The Worchester Regional Airport is at 1,009 feet above sea level and 3 miles west of Worchester (SkyVector, 2014); the distance from town and the elevation may reduce the air temperature measured at the airport.

quarter of the stations averaged 62-72 degrees, while the hottest quarter of the stations averaged 77-91. [2] Additionally, the map's overarching trend is less important when we consider the variability of those stations over the study period, which is visually represented in Figure 2. The greatest variation within one station over the study period at 57° and the greatest spatial variation between stations on one day was 20°. This difference makes it apparent that both are needed for an accurate analysis.

Figure 3 displays the raw station maximum temperature data over the study period and Figure 4 illustrates the average daily maximum temperatures of all the stations. These two figures allow one to visualize the overarching temporal trend throughout the study period. In mid-April, there is a spike in temperatures but then the temperatures return to the mid-50's until mid-May. The middle of June is the beginning of the longest stretch of hot temperatures and it doesn't cool off entirely until the end of September. The various maps included in Figure 5 display brief snapshots of the spatial variation throughout the study period. The highest temperatures are indicated by the lighter colors while the darker colors are the cooler temperatures. These maps indicate the spatial variation in the daily maximum temperatures. As a result, we found that exposure throughout the entire study period is not uniform and a combination of the spatial and temporal variation needs to be considered in further exploration.

In order to work with the spatial and temporal variation, we grouped dates during the summer into different heat wave groups. These groups are visually described in Figure 6, i.e. heat wave group 1 included April 16-18, group 2 was May 20-30, group 3 encompassed June 20- August 18 and group 4 consisted of August 23 – September 9.

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[2] Unless otherwise noted, the choropleth maps are shaded using quantile classification whereby each sub-group includes the same number of cases (subject to rounding).

Vulnerability

In Appendix D, Table 2 lays out the various Moran's I values for each of the individual vulnerability categories. The vulnerability categories with the highest Moran's I are those categories with strongest spatial auto correlation; these include the percent of population above 65 years (with a Moran's I of 0.1408), percent of population that is not white (0.1157) and the percent of land without green space (0.1107). None of the Moran's Is are terribly high which indicates limited spatial autocorrelation throughout the study area; however, using the pseudo p-value, they are all statistically significant to the 0.001 level which shows that where there is clustering, it is statistically significant.

These numbers aside, the cluster maps in Figures 7-13 further explain this relationship but provide an idea of the degree to which spatial clustering occurs. With most of these maps, there appears to be at least some relationship between the spatially weighted tracts and those tracts without the spatial weights matrix. This provides us with an understanding of the extent to which each of the census tracts may be related to its 6 nearest neighbors. The high-highs, noted in dark red, are those areas where the high values of census tracts correlated with the high values of its neighbors. The dark blue indicates where the low value census tracts correlate with the low value of its neighbors.

Each of the maps shows different relationships that exist between census tracts. However, one theme that remains through each of these is that there appears to be clustering at a larger scale than the town level. For most of the vulnerabilities, the scale at which clustering occurs appears to be regional. This is particularly visible for the high-highs among the percent of population above 65 years, the percent of green space and percent of population living alone.

Vulnerability Indices

Building off of the Reid et al. paper, we created vulnerability indices using the weights from the coefficients that were observed in their model. In that paper they strictly examined the relationship between the vulnerability index and hospitalization outcomes in Metropolitan Statistical Areas and had access to air conditioning type and diabetes prevalence (Reid, et al., 2009). During our analysis, we did not have access to this data for all of Massachusetts. Therefore, we strictly examined the social isolation vulnerability index and the social / environmental vulnerability index and excluded diabetes and air conditioning prevalence from those indices. The below formulas were used for our indices:

Social / Environmental Vulnerability Index =
([Percent in Poverty]*0.87) + ([Percent Not White] *0.85) +
([Percent Living Alone] * (-0.06)) + ([Percent 65 and Above Living Alone] * 0.19) +
([Percent 65 and Above] * (-0.32)) + ([Percent without High School] * 0.85) +
([Percent of Land without Green space] * 0.54)

Social Isolation Vulnerability Index =
([Percent in Poverty]*0.18) + ([Percent Not White] * (-0.05)) +
([Percent Living Alone] * 0.91) + ([Percent 65 and Above Living Alone] * 0.87) +
([Percent 65 and Above] * 0.38) + ([Percent without High School] * (-0.06)) + ([Percent of Land without Green space] * 0.33)

The Social/ Environmental Vulnerability Index among census tracts in Massachusetts ranged from 3 to 169 with a standard deviation of 29 and a mean of 54. The Social Isolation Vulnerability Index ranges from 1 to 148 with a standard deviation of 21 and a mean of 64. This information is found in Table 3. The spread of both indices indicates that the vulnerability is not evenly distributed in all geographies in Massachusetts.

The relationship is made even clearer through the quartile maps in Figures 14 and 15. Both maps indicate that the most vulnerable parts of the state are found in the most densely populated portions. The Social/Environmental Vulnerability Index highlight urban environments further because of the heavier weighting for the absence of green spaces; however, this may fail to capture some of the benefits of being in an urban environment during a heat wave including the accessibility of air conditioned public spaces. We later exclude the Social / Environmental Vulnerability Index from our analysis due to the likelihood of mixed effects between the temperature data and the impact of green spaces.

Combination

When we combined the temperature data with the vulnerable populations data, we found that the maximum population at an increased risk to heat-related adverse health outcomes during one day was approximately 1.01 million people (1,078,708 people). The mean number of people at increased risk on the days with temperatures above 86° (58% of the days in the study period) were 96,000 (95,940) with a standard deviation of 269,414 due to 42% of days not having anyone at increased risk, i.e. during 42% of the days the 86° threshold was not experienced in any of the census tracts and therefore no people were exposed. These temporal trends are visualized in Figure 16 and 17 of Appendix E.

Using the heat wave groups identified in the weather portion of this study, we found that for the first, second and fourth heat waves during 2012, the clustering of exposed populations was among larger regions of the state than we saw in the initial clustering. This makes it clear that when a heat wave occurs it is likely to impact the state regionally, at the scale of counties, emergency preparedness zones or regional planning agencies.

The dot density maps in figures 22-25, display how even with the vulnerabilities, the population impacted may be fewer than what one would expect if strictly looking at the choropleth maps. This is particularly evident when one compares heat wave group 2 with the other 3 heat wave groups. The other three heat waves seem to have exposed more people who were vulnerable than in Group 2.

Discussion of Spatial Analysis

The aforementioned analysis and data exploration provided some interesting insight into the heat wave vulnerability of populations in Massachusetts. The major finding of the weather analysis showed how the temperature exposures throughout Massachusetts can vary and the hottest location during one heat wave or one day is not always the hottest location during the next. Therefore, it is necessary to combine the temperature variation data with the vulnerability data in order to better assess the temperature exposure that Massachusetts' residents likely experienced during the study period.

The vulnerability analysis without the inclusion of the weather data allowed us to examine the how the vulnerabilities are spread throughout the state and made it abundantly clear that vulnerabilities are not evenly spread throughout the state; some vulnerable populations are more clustered than others. This clustering by itself is one argument for a regional approach; however, when we added the temporally unique weather data to this, we found that when heat waves occur, they often do not isolate themselves to one community's vulnerable people. This analysis describes how critical it is to think about heat wave emergency response resources at a regional scale throughout Massachusetts.

Chapter 5: Conclusions and Recommendations

Best Practices

When we compared the three different heat-event response guides, we saw an emphasis from the United States based sources on individual-level interventions and emergency response. The WHO approached heat-related issues more holistically and described policy measures that could improve the built environment to reduce communities' exposure to extreme heat. All of these recommendations ought to be considered by policymakers for the commonwealth of Massachusetts and by local officials throughout the state. Nevertheless for the purposes of this thesis, we focused on emergency response during heat events.

The individual level interventions that were provided by both the WHO and the CDC are directed at the general population and are likely the standards that MEMA, public health officials in the state, and other municipal leaders can use to provide guidance to the general population. The EPA's description of the notification and response interventions is the most detailed; it outlines specific steps by which communities should organize. These steps likely have a spatial component and could be taken at a local, regional or statewide level depending on the heat event's extent or the type of resource. For instance, the cooling centers should likely be provided at a local level while the heat-related informational phone lines could be provided at a statewide or regional level. The increased outreach to health care professionals and evaluation of high-risk individuals should likely take place at a regional level. The coordination of public broadcasts could and should come from any and all of the aforementioned scales in order to ensure that the broadest population is reached. Yet these efforts should not duplicate but rather enhance the work that others are attempting to reduce exposure implying that coordination is necessary.

Massachusetts' Policies

Massachusetts has some innovative policies to help its residence weather the impacts of extreme temperature events. For instance it provides utility shutoff protection during extreme temperature events to allow air conditioning, fans and other cooling devices to remain on or in the case of extreme cold, heaters. Additionally, MEMA identifies itself as the primary statewide actor in the case of any extreme weather event. However, much of the 'on the ground' assistance provided to residents comes from the municipalities themselves. This general practice may impact the vulnerable populations living in communities with less comprehensive event response infrastructures. While some communities have quite thorough response strategies with varying levels of interventions and clear indication of actors who ought to be involved at each stage, other communities lack this. Some communities have a systematic approach of contacting their vulnerable populations because of established networks while others resort only to broad sweeping messages; e.g. press releases from the mayors' offices posted on their website. It may be valuable for smaller municipalities to pool resources and create a network of regional players who are capable of accomplishing the needed response.

Spatiotemporal Analysis of Vulnerable People and Weather

By examining the vulnerabilities without the spatiality of the weather, we found that many census tract-level vulnerabilities are not spread evenly throughout the state and clustering does occur. The clusters of vulnerabilities make it evident that some areas may need more assistance and resources than others when large areas of the state are affected by a heat event. From the various maps that combine the spatiotemporal variation in weather and the social isolation vulnerability index, we saw that the heat events' spatial distribution can vary dramatically. For heat events that fall in groups 1, 2 and 4 during the 2012 summer, a regional approach makes the most sense. For the third heat event, the entire state ought to respond. The statewide, resource-intensive response may be best organized by one large statewide agency that has branches in each of the emergency response regions. During the more regionally-specific events, this statewide agency could have specialists who move throughout the commonwealth to provide technical assistance to the impacted regions as they are affected.

Recommendations

The above findings suggest that Massachusetts may be able to make its heat-event response work for impacted communities more effective. The below recommendations tie the findings together while being loosely based on Bernard and McGeehin's 2004 best practices and the aforementioned heat event response guidelines. While we did not outline specifics regarding the stages of a heat event response plan, an excellent model for the state is the three stages used by Boston. Ideally, employing all of the best practices noted in Table 1 of Appendix B would be recommended; however, given our limited understanding of the full capabilities of existing resources and staff, we suggest the following overarching recommendations:

Clarify the Statewide, Regional and Local Response Leaders

By more clearly defining the primary actors and their roles at the state and regional levels, Massachusetts may better pool resources across sectors, temporally and spatially. Currently MEMA describes itself as the primary agency for coordinating the response to all emergencies; however when it comes to heat events, they state that public health officials are responsible for reaching out to vulnerable populations. They don't specify whether those health officials are at the state, local or regional level. This leads to confusion around who ought to do what during an extreme heat event. The resulting transparency of this change may make the below recommendations more feasible and effective. We propose having MEMA delegate specific steps of the response as they do with other emergencies. MEMA should specify that public health officials perform other tasks including reaching out to health care providers and maintaining lists of vulnerable populations who should be contacted at different stages. This may require MEMA to hire or reassign people who are responsible for other extreme temperature events to assist in coordinating extreme heat events.

If public health officials are to lead the efforts, there should be clarification from MEMA that describes the roles of other players who are to work with the public health officials contacting vulnerable people; these outreach efforts ought to be similar to the type of explicit plans they have for floods. This includes tying public health outreach to other wellness calls that police and fire departments may already make during other emergencies. Public health may also serve as a strategizing partner that provides updated lists of vulnerable people throughout Massachusetts communities in order to reduce the workload of municipalities attempting to contact vulnerable individuals. This includes using Medicare and Medicaid data for later-stage door knocking campaigns or earlier telephone calls.

Standardize the Scale of the Warning System

The weather and vulnerability output indicates that the state ought to develop a statewide and regional approach to extreme heat events. When it comes to resources, this may be more challenging than the less centralized municipalities operating independently when they are impacted by a heat event. Using the NWS's prediction systems with the 86° threshold and allowing for 5-day warning system, the scale ought to be easily estimated in order to target the appropriate players.

As a result, the solution may differ according to the scale of the emergency. One example of this is if the affected area is small enough for one region to handle the emergency alone. As seen in the case for heat event groups 1,2, and 4 from 2012 (visualized in Figure 6 of Appendix C). Those types of events may require a regional approach with a statewide coordinator moving between them. However, as we saw with group 3, some longer heat events are likely to impact everyone in the state. This makes the shared experience of these larger scale events potentially more dangerous while also opening the commonwealth up for greater coordination among the players responding to the emergency. By having the regional systems in place and a statewide coordinator, the state may most effectively impact the broader scale while also being able to downsize efforts when the events are only impacting specific regions.

Communicate the Risks Involved and Educate the Population

Sharing knowledge around the heat response would provide one of the greatest benefits of a statewide and regional response system. For instance some communities are more effective at communicating with the news outlets than others, while still others are better at coordinating efforts across disciplines and are able to extend the hours of swimming pools without much resistance. The regional approach would allow for a reduction in effort duplication. Instead of one mayor's office attempting to notify the local community and another duplicating this effort in his or her own municipality, sharing this responsibility between municipalities might reduce the workload for that particular region. Additionally, by sharing information and communication approaches across communities, risk communication and public education ought to become easier. Sharing information may come in the form of MEMA or public health staff gathering local and regional stakeholders together in order to promote more visible discussions of best practices and assigning roles of specific players during the heat event response.

Target High-Risk Populations

If the players are capable of coordinating actions, it could be beneficial in other ways. One approach to contacting high-risk people is to create a shared call center that informs and checks on individual households if there is an emergency. Additionally, building a health care provider network may be valuable to reach affected households. It may simply be easier to build this network regionally or statewide rather than for every locality. Overall regional coordination may make a campaign to reach out to vulnerable populations more feasible for many of the municipalities in Massachusetts. Where possible and for extreme heat events that include power outages (or brownouts due to over use of electricity), home visits may be called for. In those rare cases, having the regional network will be critical to provide enough man-hours for the most vulnerable and affected locations.

Evaluate the Efficacy of the Plan

Any plan that is not evaluated well could likely have problems. Therefore, it is critical that the statewide leader in the heat event response also leads in evaluating the plan's efficacy. Due to the impact of heat events on health outcomes, this could involve work performed by public health officials to determine the best evaluation strategy. It likely will involve looking at the relationship of hospital admissions and extreme heat events before and after the implementation of the new plan. If it is apparent nothing has improved, than the plan should be reevaluated for future actions.

Conclusion

With the impending increase in temperatures during the summer, Massachusetts is likely to face an increase in droughts, pests and heat-related hospital admissions. As the temperatures rise, we will also likely to see a larger percentage of the population air-condition their homes and, as a result, a strain on energy systems. MEMA repeatedly states in their severe weather plan that critical facilities will likely not be affected by extreme heat events unless there are brownouts due to too many people using air conditioning at once. However, like other emergencies including flooding and droughts, extreme heat affects regions at a time rather than strictly one municipality. This would therefore make building off of other emergency response systems relatively natural. One clear advantage to ramping up heat event response is that it requires less equipment than many other emergencies. Additionally sharing resources among regional players, may allow for a more comprehensive response to heat events including reaching out to vulnerable people and ensuring their safety.

Limitations

While this analysis found some interesting and valuable information, it is not without problems. Although we initially intended to examine the relationship between hospital admissions and heat, we were not able to do so because of data access issues that arose. Additionally, we were not able to examine the heat-related long-term, non-emergency response for the state of Massachusetts. This would include policy changes that could mitigate the urban heat island effect e.g. green building codes. We were not able to include these longer-term strategies in this project because of the scale of this project. We were also unable to compare vulnerabilities to actual health outcomes. We needed to base our indices on previously peer-reviewed articles that found little association between hospital admissions coded specifically for heat-related diseases and the vulnerability indices in Massachusetts while nationally there was a much stronger relationship between heat-related hospital admissions and the same vulnerability indices. That being said, in Massachusetts the relationship between the vulnerability indices and all-hospitalizations was strong. Additionally, the weather modeling we used was strictly based on inverse distance weighting interpolation of maximum daily temperatures; it could have been improved if we had used another source's weather model that accounted for topography, wind variation, humidity, air quality and other climate related components. The weather analysis could have also been improved if we had been able to incorporate the actual threshold for Boston which is 86° Fahrenheit and 40% humidity.

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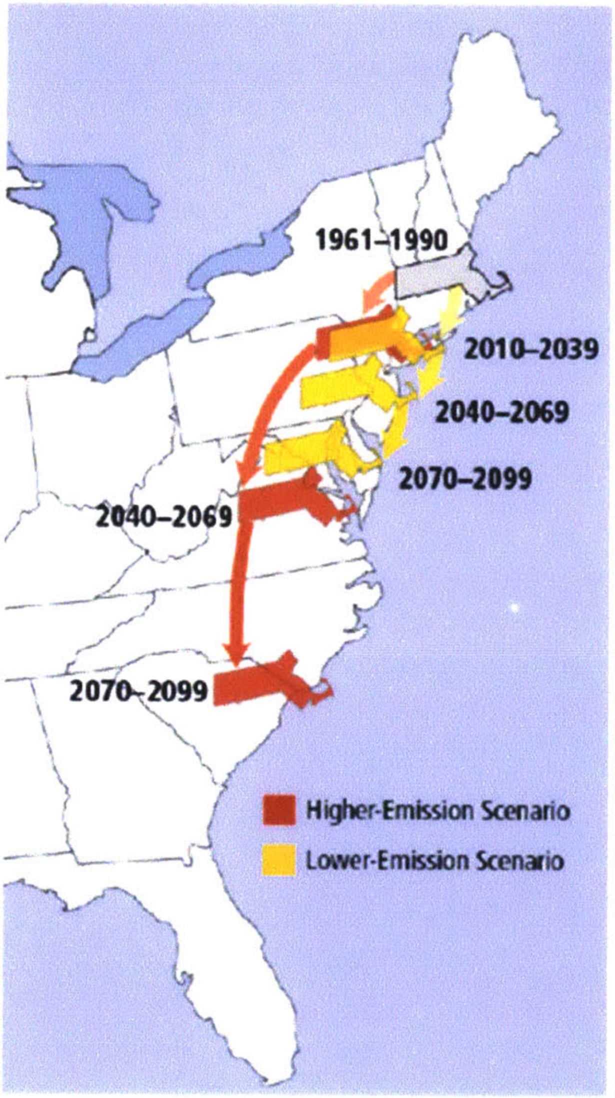
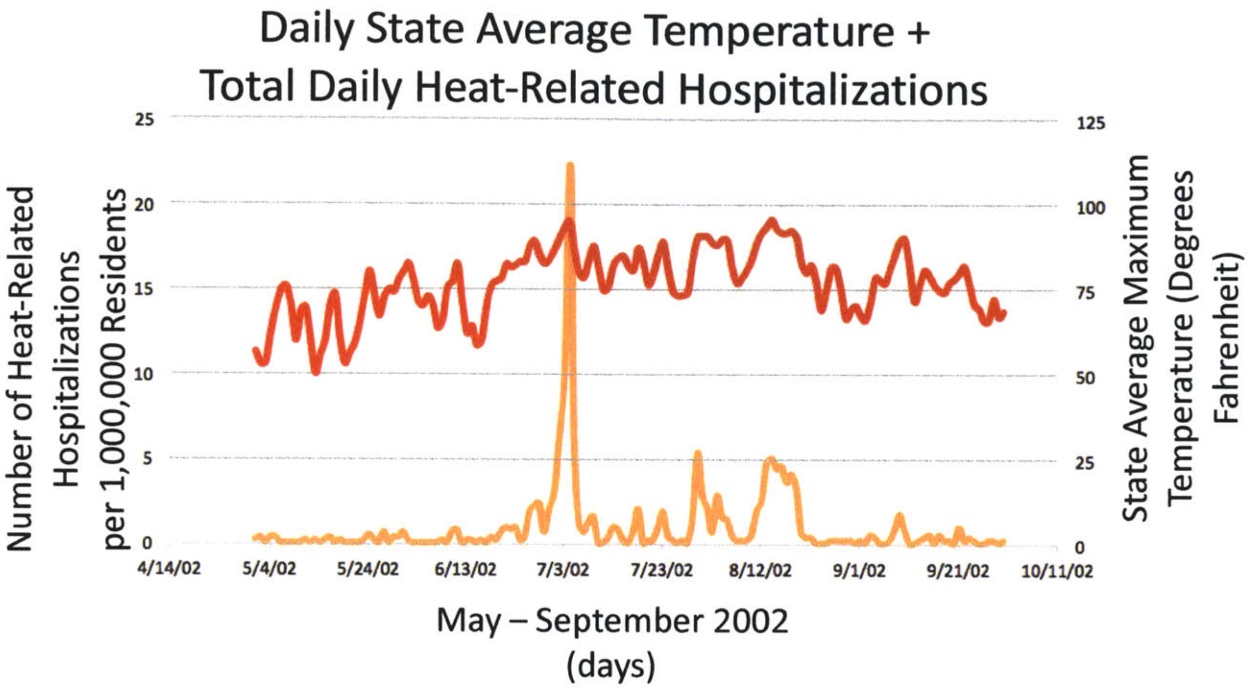
Appendix A. Background Information

Image 1. A pictorial representation of the estimated changes in temperatures for Massachusetts



(Union of Concerned Scientists, 2006)

Image 2. Graph of Massachusetts' Summer 2002's Heat-Related Emergency Department Visits and Average Daily Temperatures



Appendix B. Best Practices

Table 1. Comparison Table of Best Practices

	EPA	WHO	CDC
Individual-level Interventions			
Wear appropriate clothing and sunscreen			X
Replace salts and minerals			X
Advice on behavior		X	X
Have access to cool spaces		X	X
Room air conditioners		X	X
Monitor people you know who are vulnerable			X
Do not leave children in cars			X
Medium-Term Building-Related Interventions			
Increase building envelope		X	
External Shading		X	
Insulation		X	
Decreasing Internal Heat Load		X	
Passive Cooling Technologies		X	
Efficient Active Cooling		X	
Long-Term Policy Measures			
Building Regulations		X	
Urban Planning		X	
Land-use Changes		X	
Mitigation of Climate Change	X	X	
Prediction			
Have the capability of determining extreme heat event conditions 1-5 days prior to event	X		
Risk Assessment			
Coordinate/evaluate weather forecasts as part of heat program	X		
Determine estimates of heat-event's health impact	X	X	
Use broad criteria to determine heat-specific deaths	X	X	
Gather information in high-risk populations	X	X	
Gather information on facilities or locations with high concentrations of high-risk populations	X	X	
Notification and Response			

Coordinate public broadcasts of information about the heat event, heat exposure symptoms and interventions to address those	X	X	X
Provide information and advice for the public by handing out leaflets and fans		X	X
Open heat-related informational phone lines	X		
Open cooling centers and provide transportation; extend hours of air conditioned community centers	X	X	
Organize extra staffers for emergency support	X	X	
Contact and evaluate the conditions for high-risk individuals	X	X	
Increase outreach to health care professionals working with at-risk populations		X	X
Increase outreach activities to transient populations in order to provide access to cooling centers	X		
Restrict or suspend utility turn offs	X		
Reschedule large outdoor gatherings to reduce direct exposure to heat	X		
Report significant difficulties and keep in contact with the emergency response department		X	

Appendix C. Weather-related Output

Table 1. Station and Temporal Variation in Temperature

Description	Short Desc.	Number	Avg.	Min.	Max.
Average Daily Maximum Temperatures Spatial Variation throughout MA, *i.e. the lowest temperature subtracted from the highest temperature on one day throughout the state (the lowest line subtracted from the highest line in Figure 4)*	Between station variability	183 days with 68 stations per day	18°	10°	36°
Within Station Temperature over Entire Study Time, *i.e. the average temperature for one station during study period (Figure 1)*	Station temperature over time	68 stations with 183 observations per station	74°	46°	95°
Within Station Temperature Variation over Entire Study Time, *i.e. the lowest temperature in one station subtracted from the highest temperature for one station during study period (Figure 2)*	Within station variability	68 stations with 183 observations per station	48°	29°	57°

Figure 1. Average of Each Station's Maximum Temperature over Entire Study Period

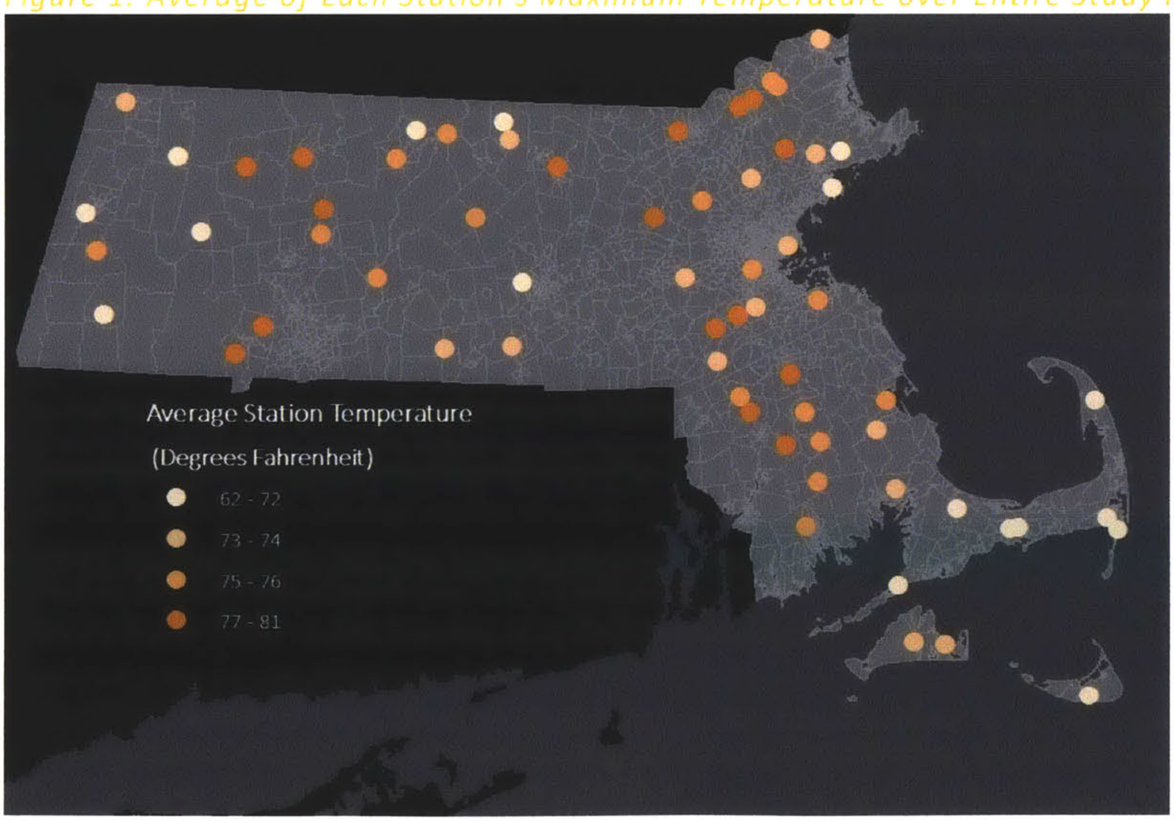


Figure 2. Within Station Variability over Study Period

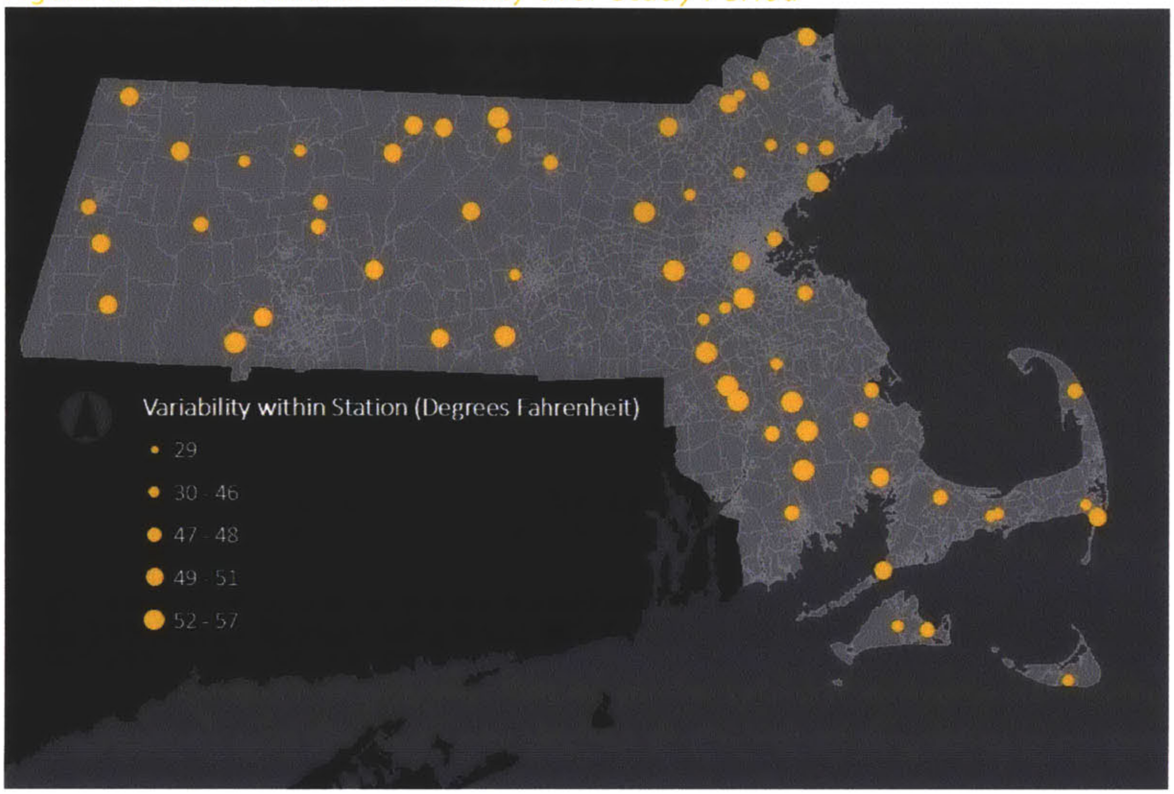


Figure 3. Raw Station Output over Entire Study Period: Daily Maximum Temperature per Station

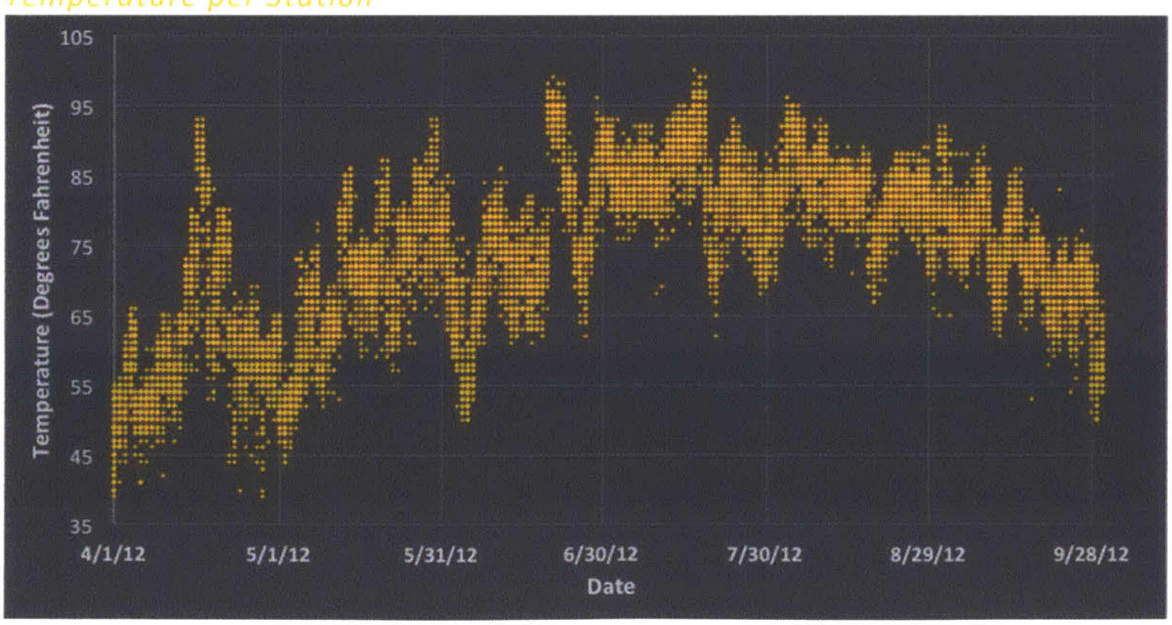


Figure 4. Average Daily Maximum Temperature over Entire Study Period

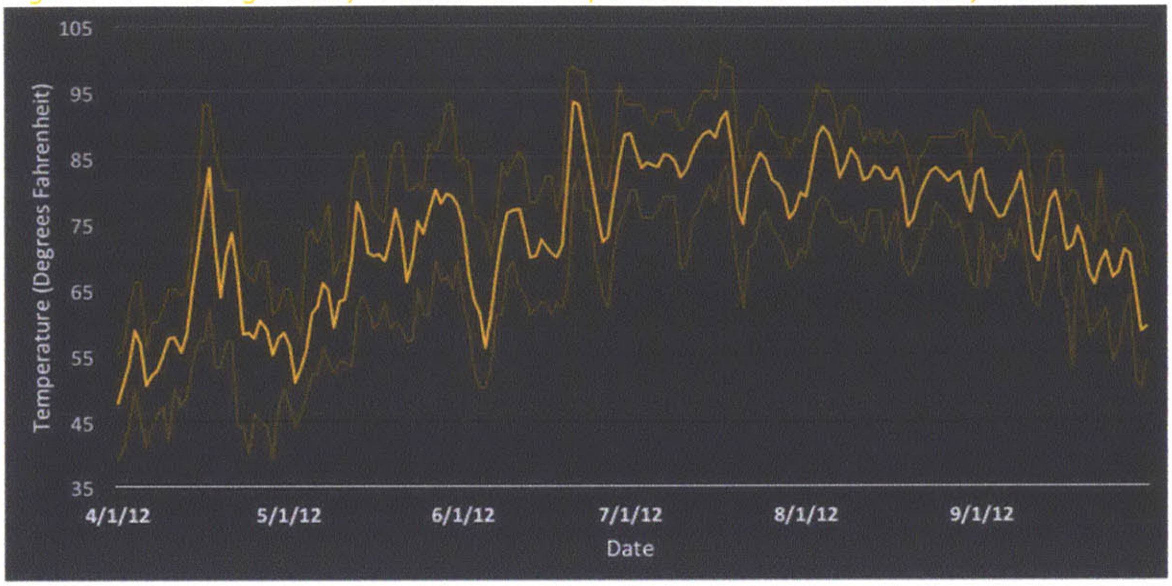
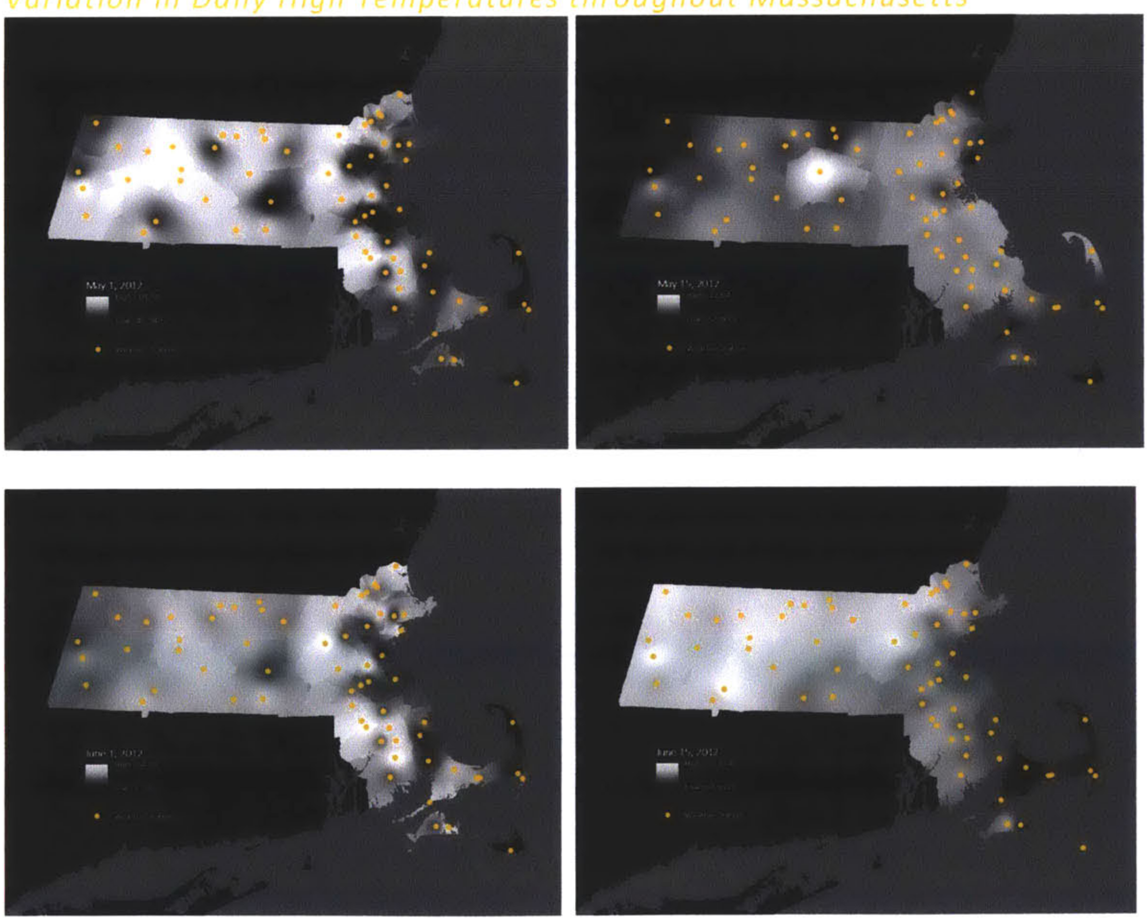
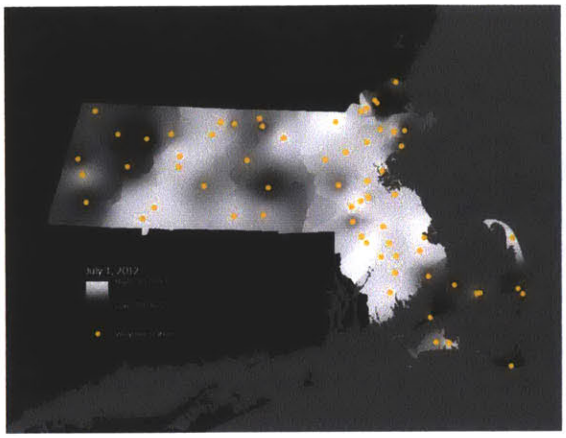
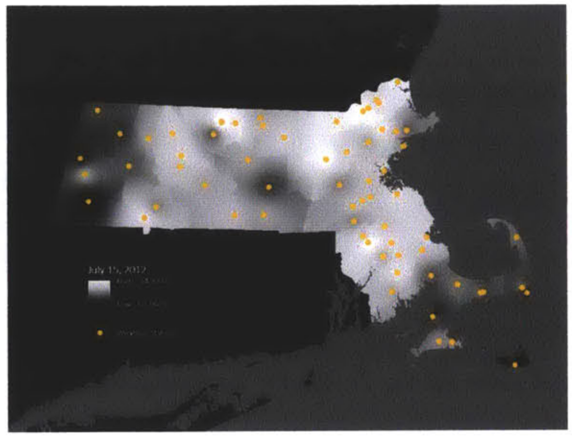
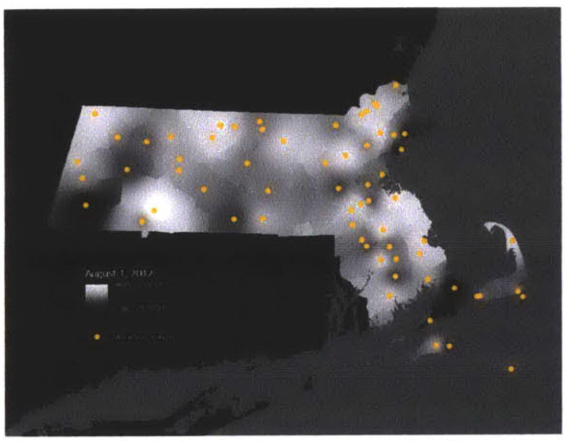


Figure 5. Inverse Distance Weighted Daily Temperature Maps Indicating Spatial Variation in Daily High Temperatures throughout Massachusetts

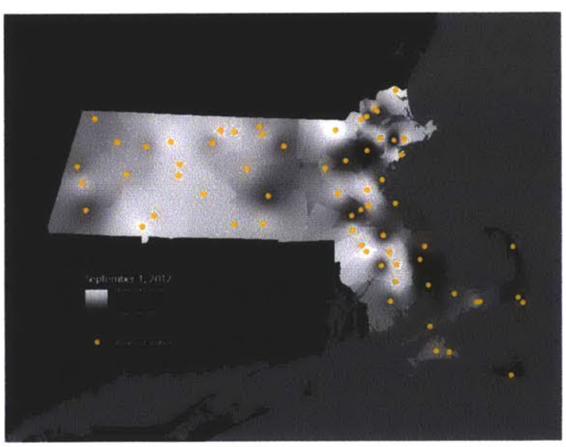



July 1, 2012


July 15, 2012

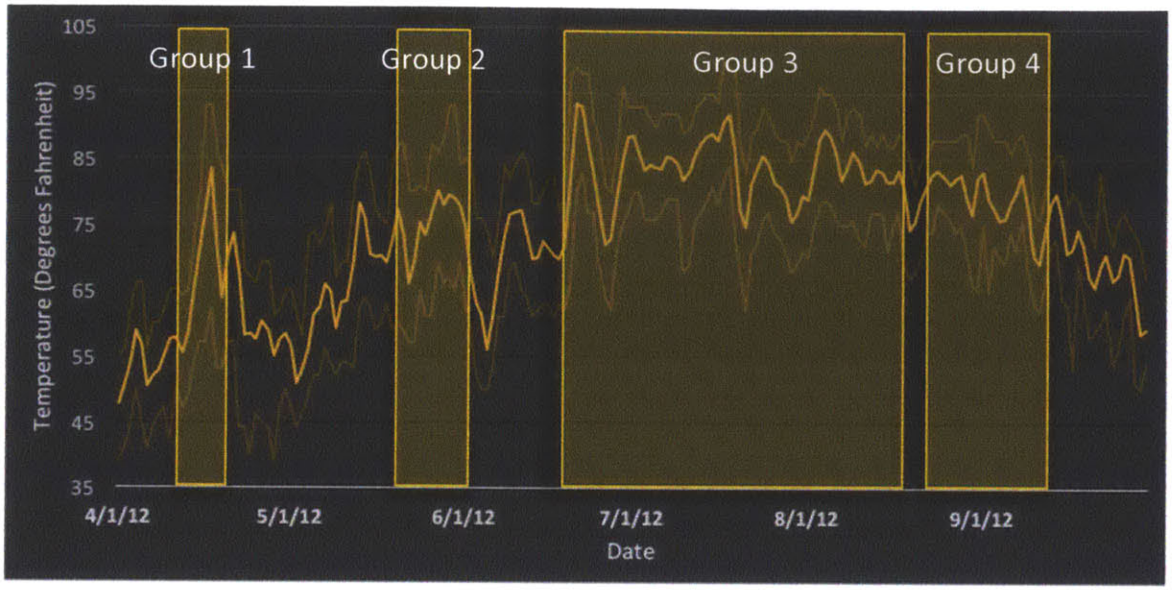

August 1, 2012


August 15, 2012


September 1, 2012


September 15, 2012

Figure 6. Average Daily Maximum Temperature over Entire Study Period with Identified Heat Wave Groups



Appendix D. Vulnerability-related Output

Table 2. Moran's I for each of the Variables

	Moran's I	999 permutations pseudo p-value
Percent above 65 years	0.1408	0.001
Percent younger than 5	0.0204	0.001
Percent of Land without Green Space	0.1107	0.001
Percent in Poverty	0.0832	0.001
Percent without High School	0.0904	0.001
Percent Not White	0.1157	0.001
Percent Living Alone	0.0769	0.001
Percent 65 and above Living Alone	0.0321	0.001

Figure 7. Cluster Map of the Percent Population Older than 65 Years

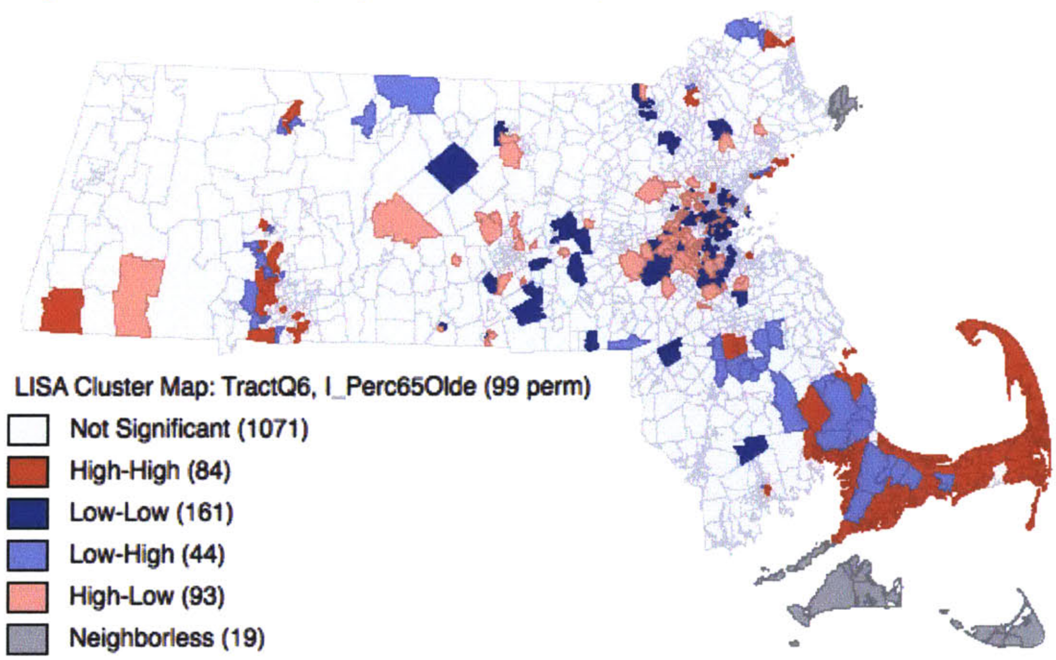


Figure 8. Cluster Map of the Percent Population Younger than 5 Years

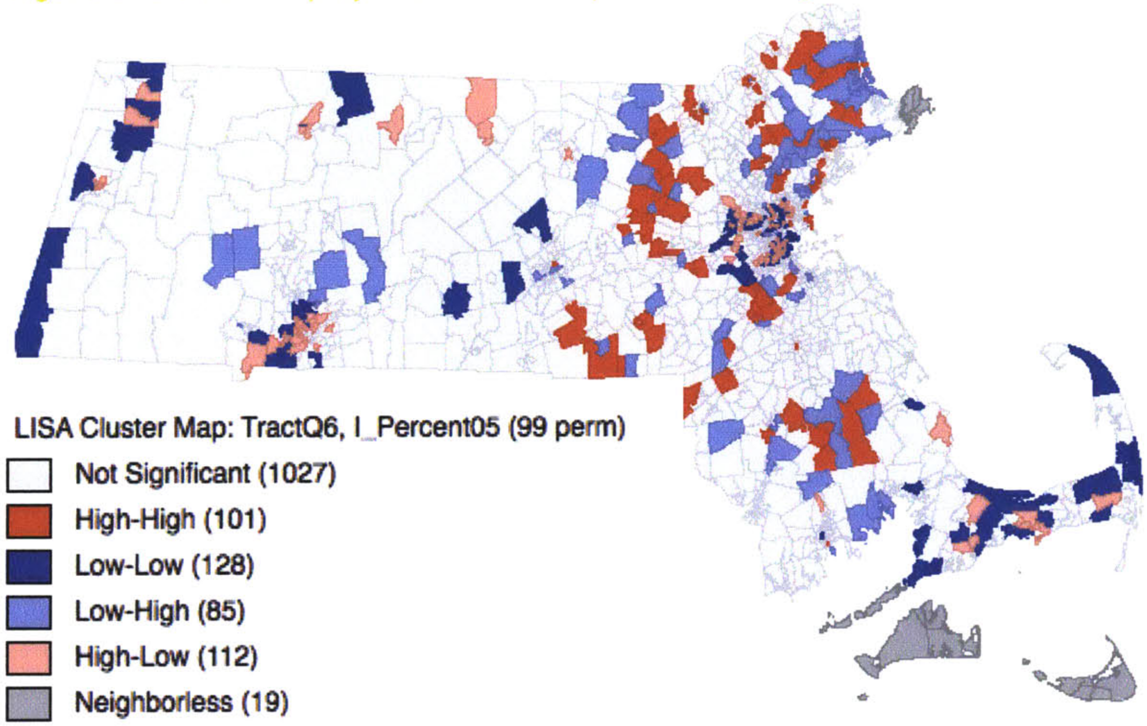


Figure 8. Cluster Map of the Percent of Green space

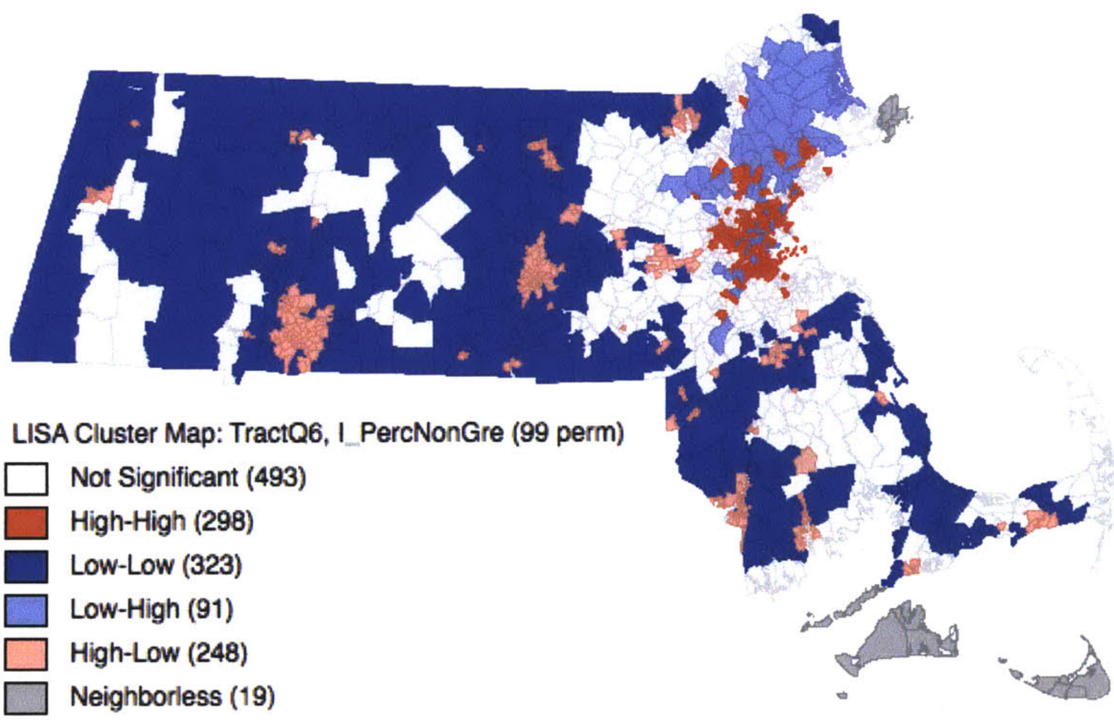


Figure 9. Cluster Map of the Percent of Population Living at or below Poverty

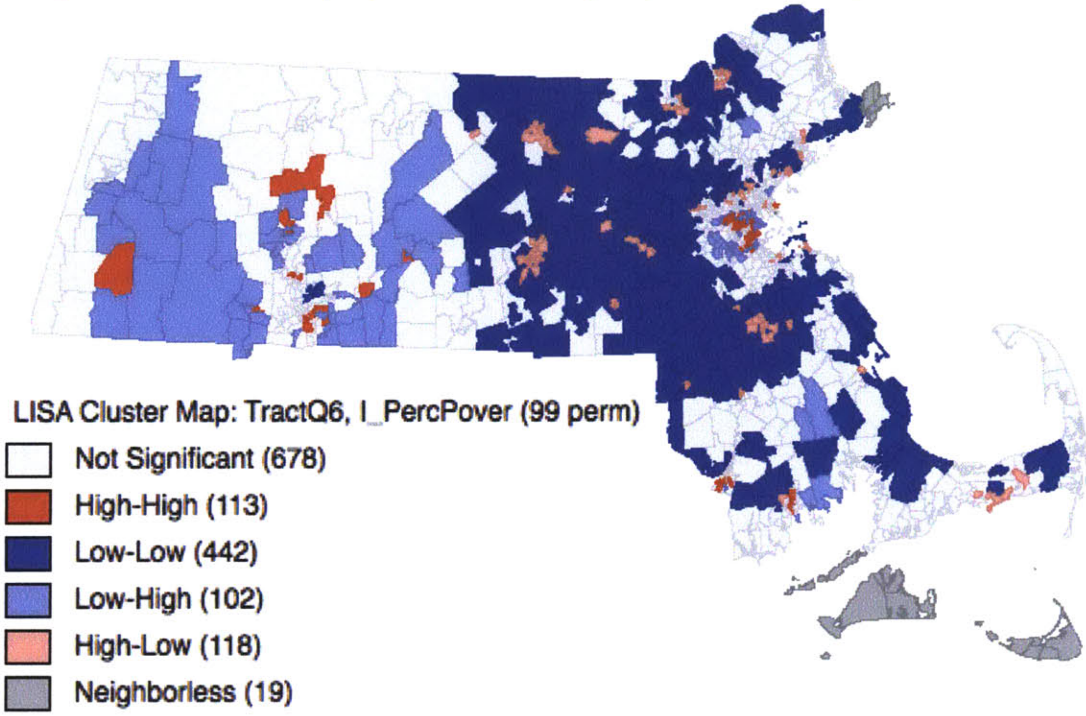


Figure 10. Cluster Map of the Percent of Population without High School

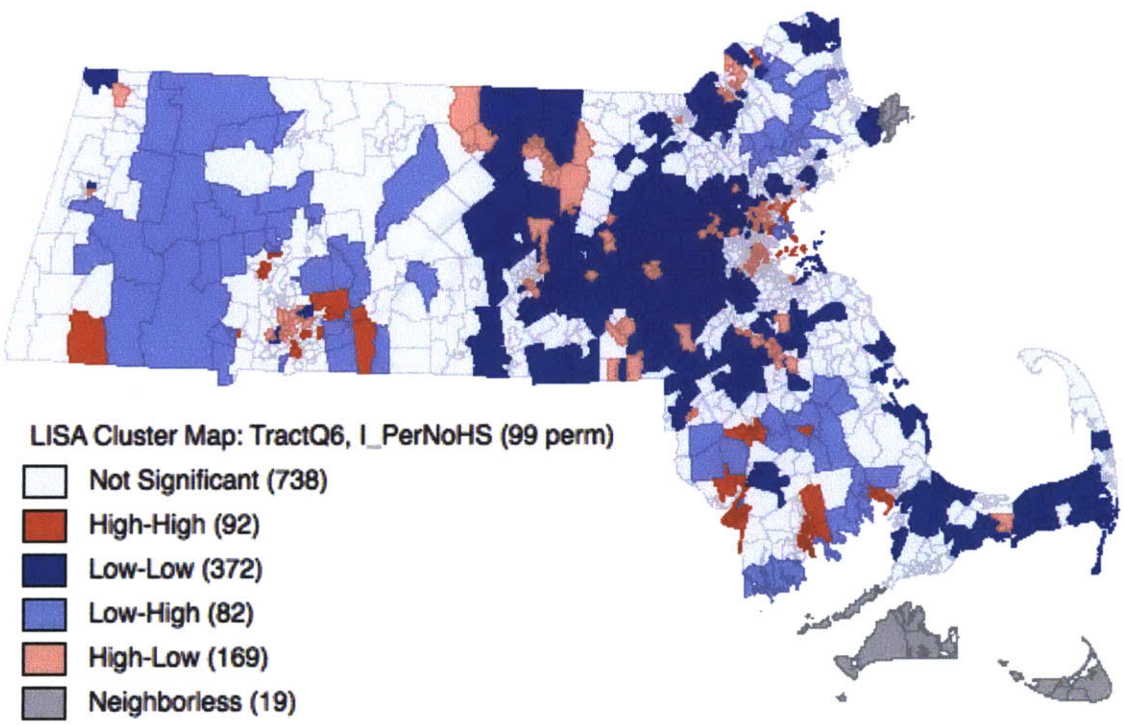


Figure 11. Cluster Map of the Percent of Population that Does Not Identify as White

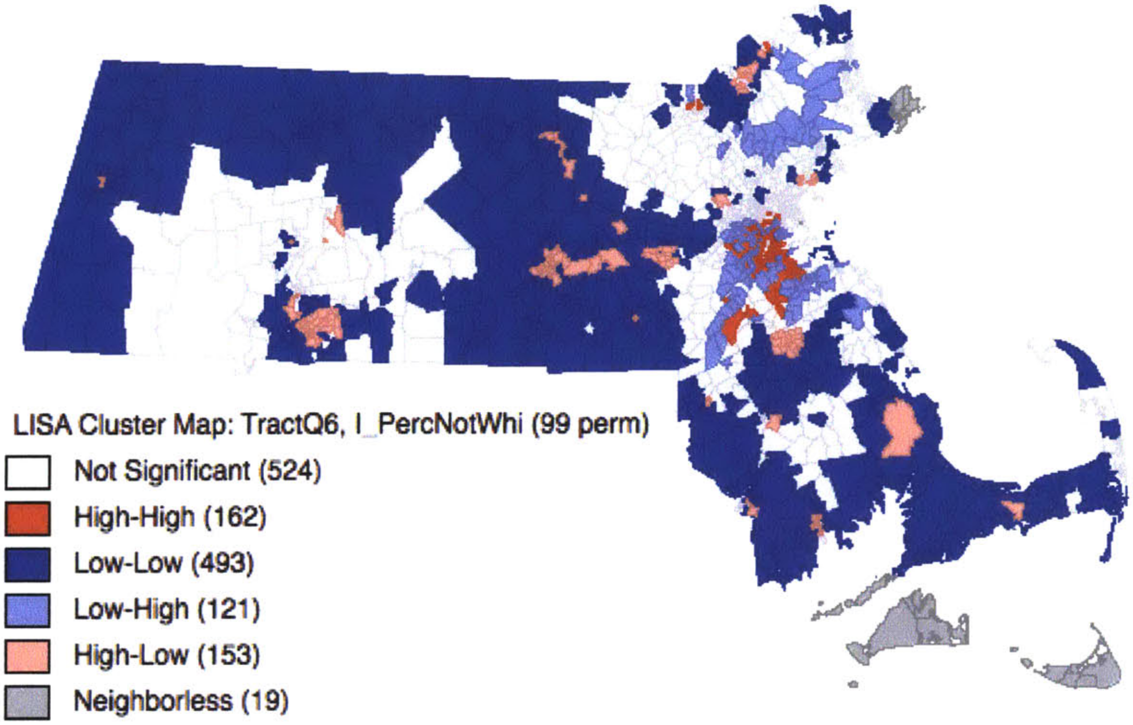


Figure 12. Cluster Map of the Percent of Population Living Alone

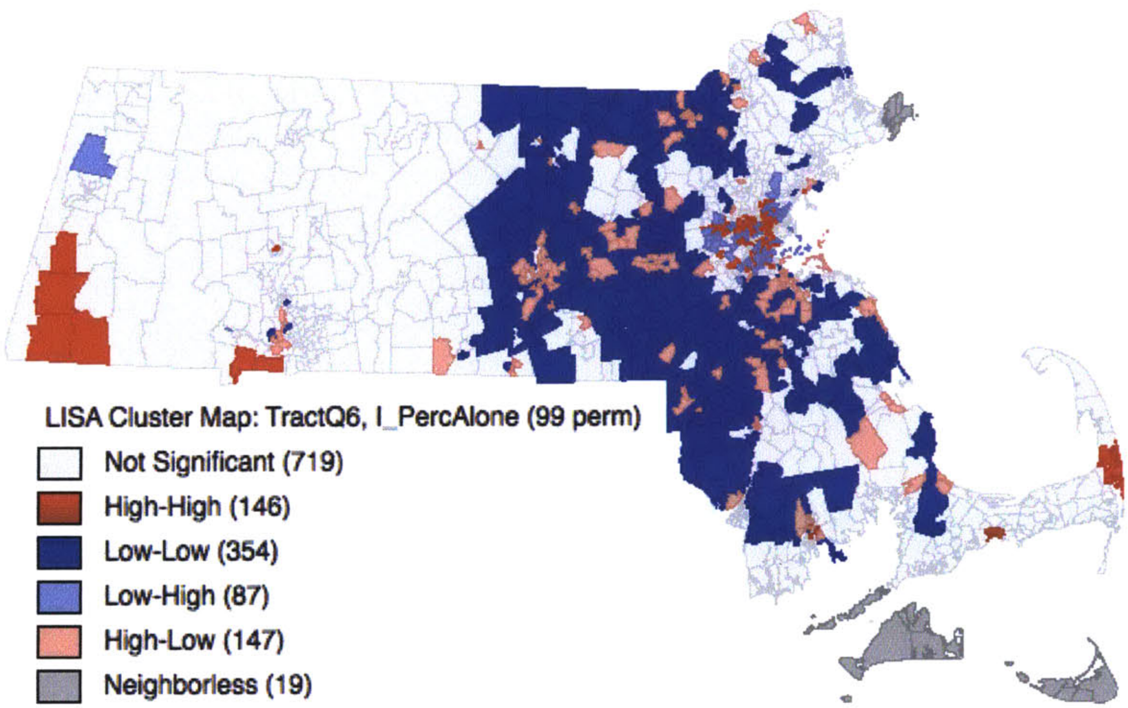


Figure 13. Cluster Map of the Percent of 65 and Above Living Alone

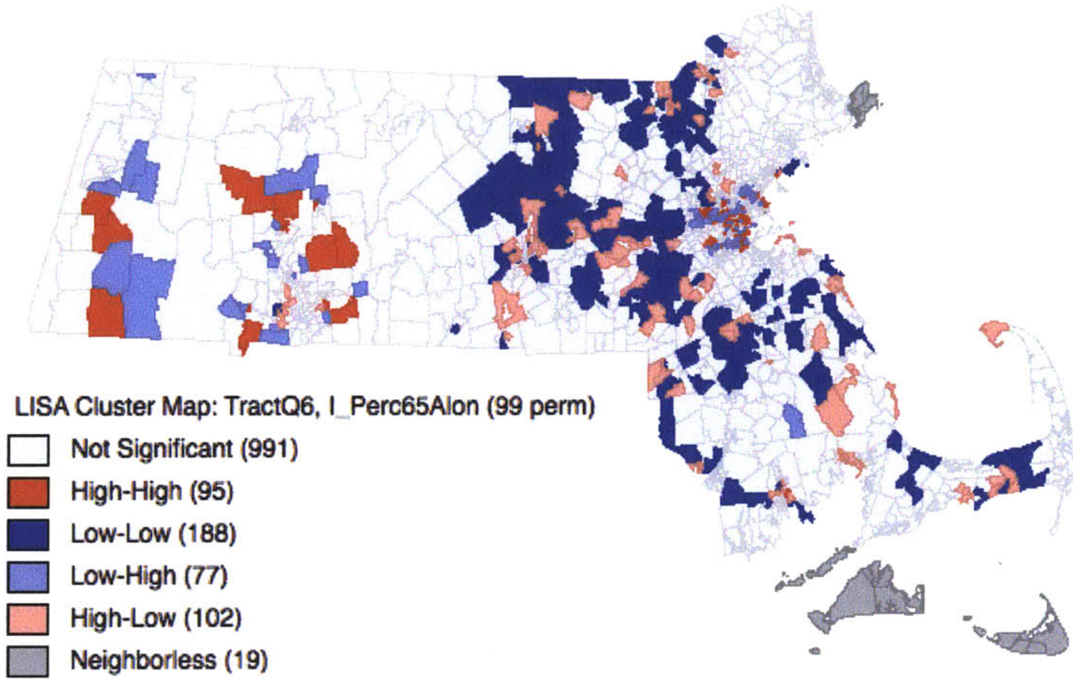


Table 3. Descriptive Statistics for Vulnerability Indices among Massachusetts' Census Tracts

	Mean	Minimum	Maximum	Standard Deviation
Social / Environmental Vulnerability Index	54	3	169	29
Social Isolation Vulnerability Index	64	1	148	21

Figure 14. Quartile Map of the Social / Environmental Vulnerability Index

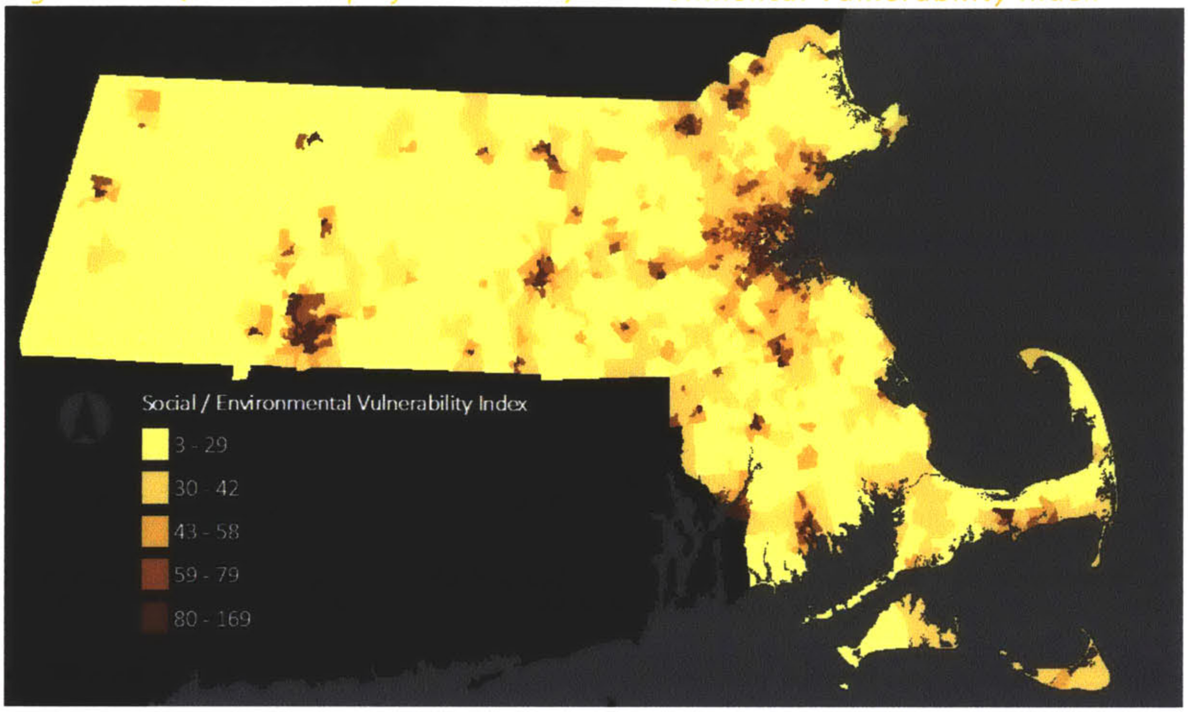
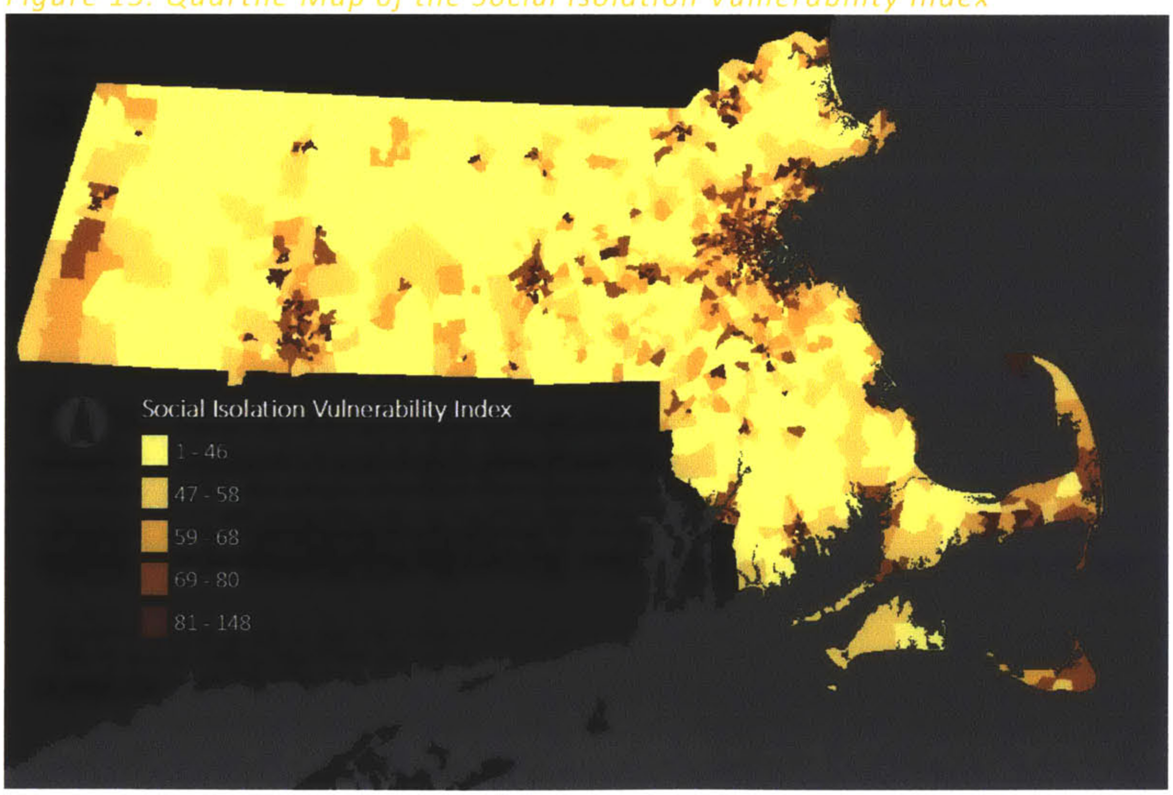
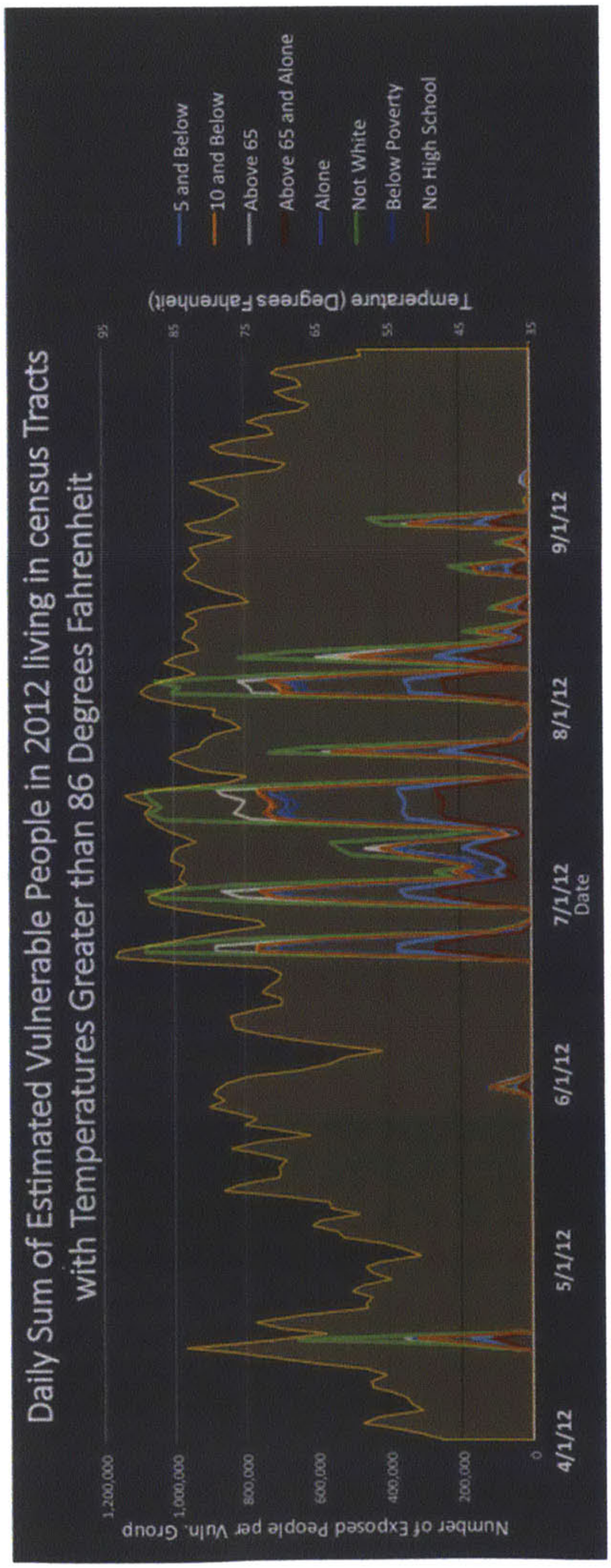


Figure 15. Quartile Map of the Social Isolation Vulnerability Index



Appendix E. Combination Output: Vulnerability Indexes and Weather

Figure 16. Temporal View of Total People Likely to be at Increased Risk of Heat-Related Adverse Outcome



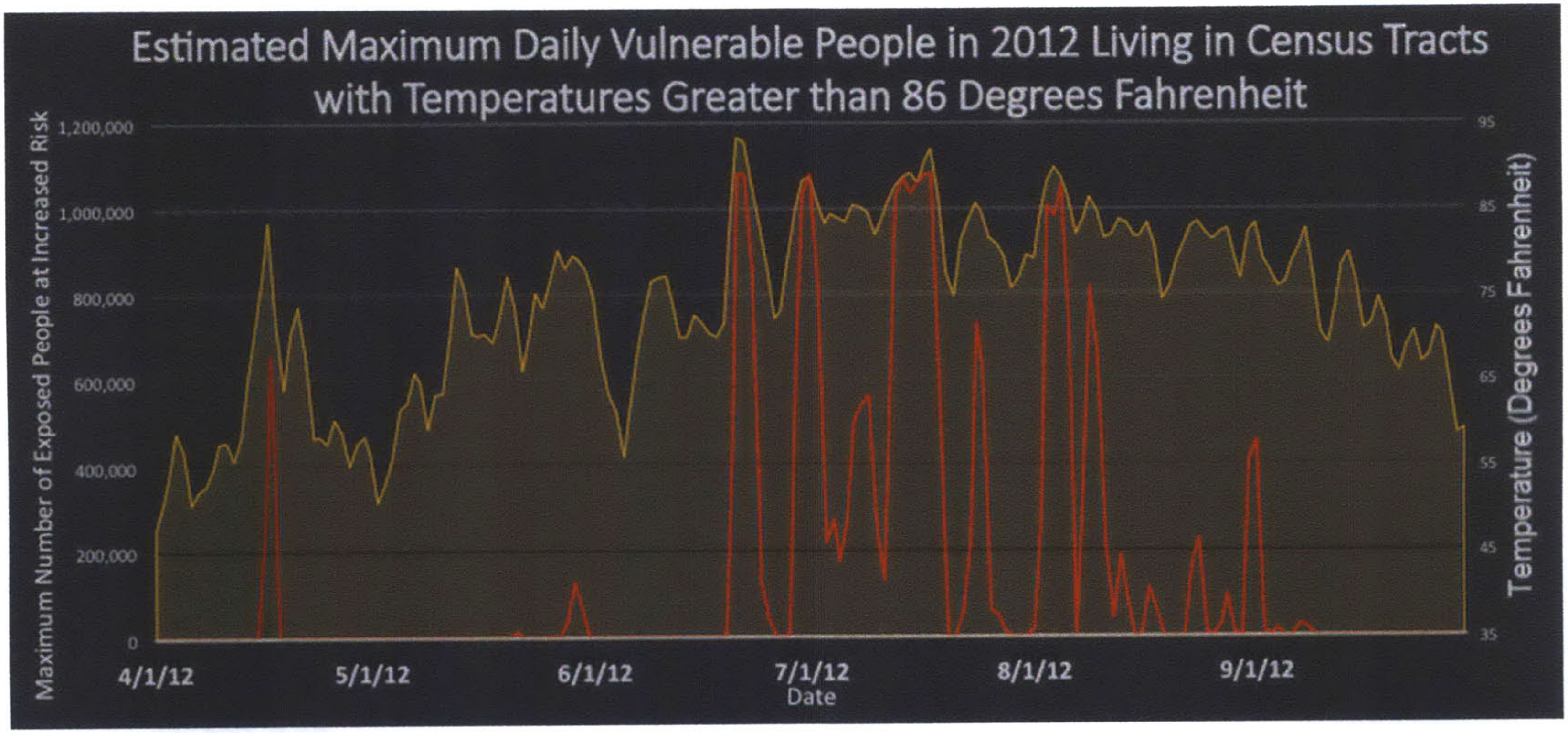


Figure 17. Temporal View of Maximum Number of People Likely to be at Increased Risk of Heat-Related Adverse Outcome

Figure 18. Group 1: Social Isolation Index

Figure 19. Group 2: Social Isolation Index

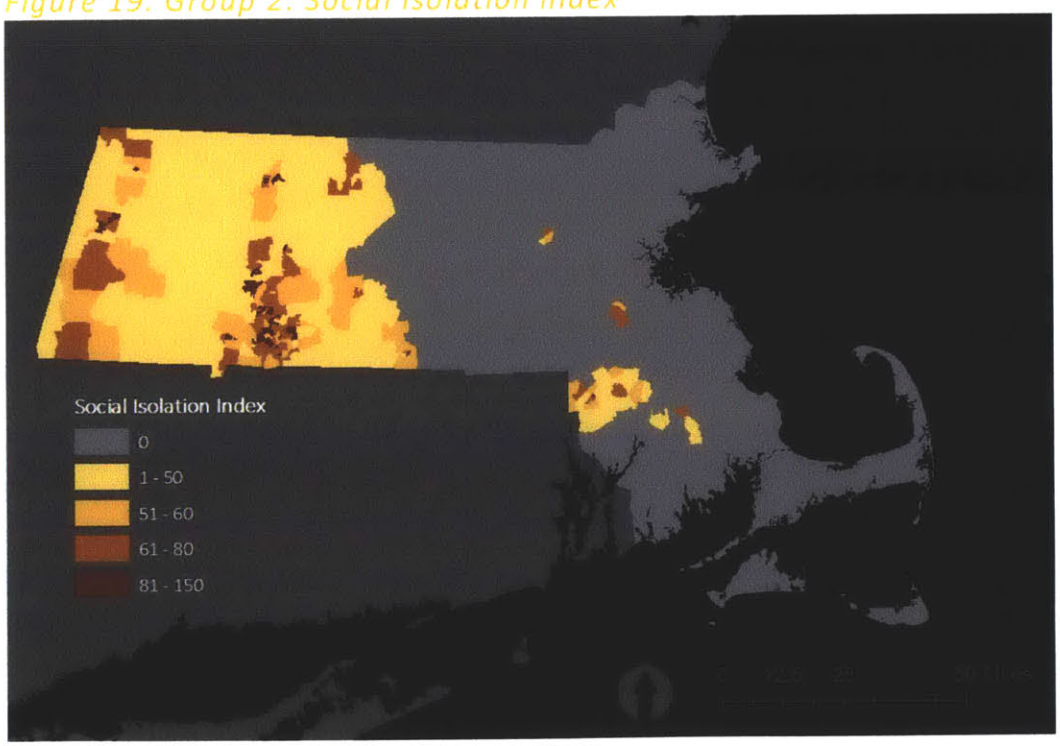


Figure 20. Group 3: Social Isolation Index

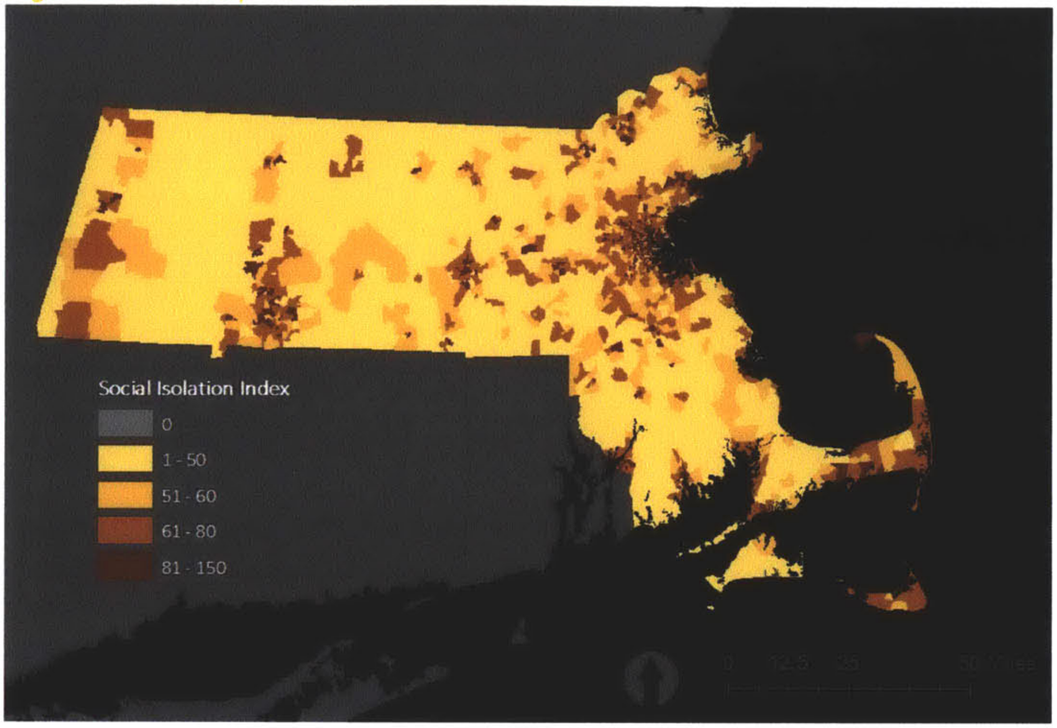


Figure 21. Group 4: Social Isolation Index

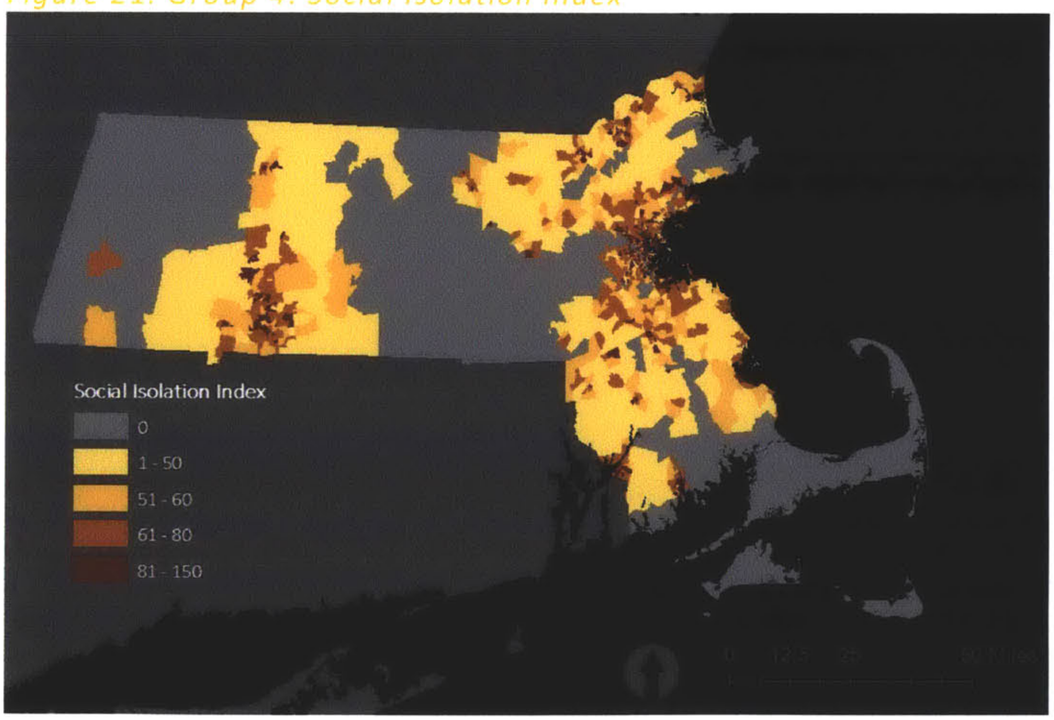


Figure 22. Group 1: Dot Density Map[3] of Populations Exposed with Differing Vulnerability Indices

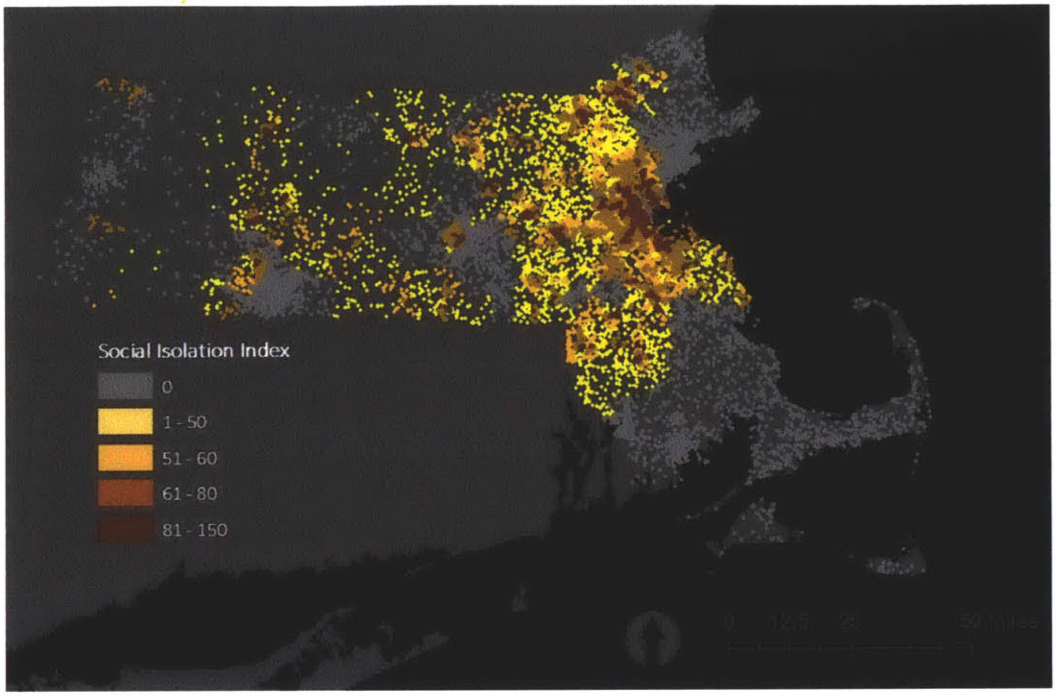
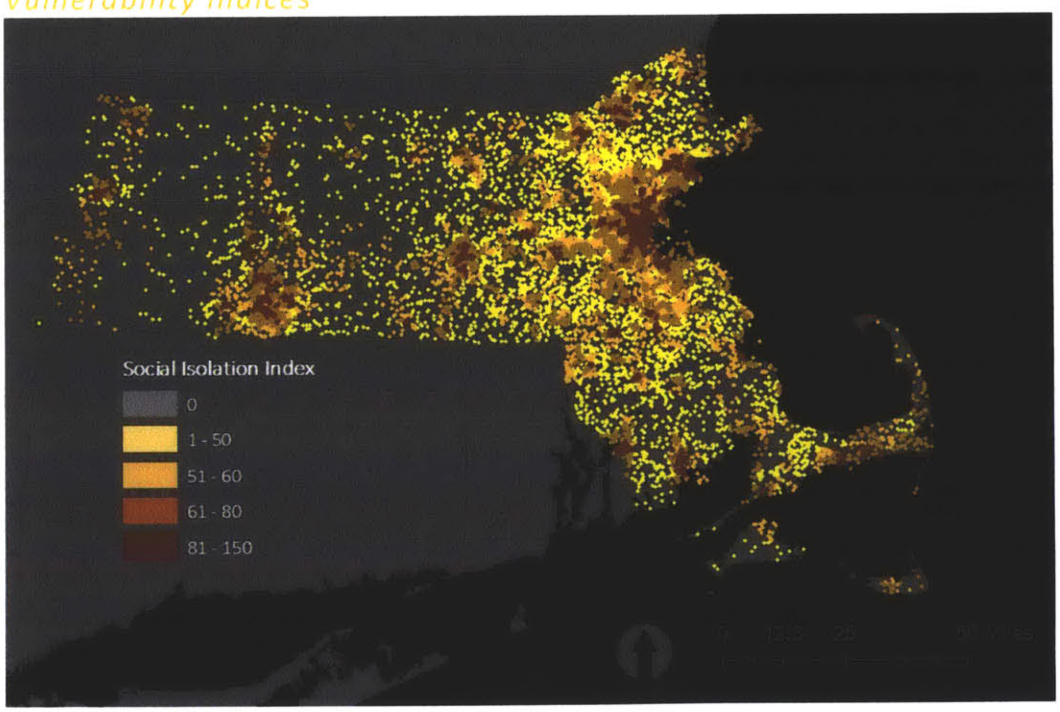


Figure 23. Group 2: Dot Density Map[4] of Populations Exposed with Differing Vulnerability Indices

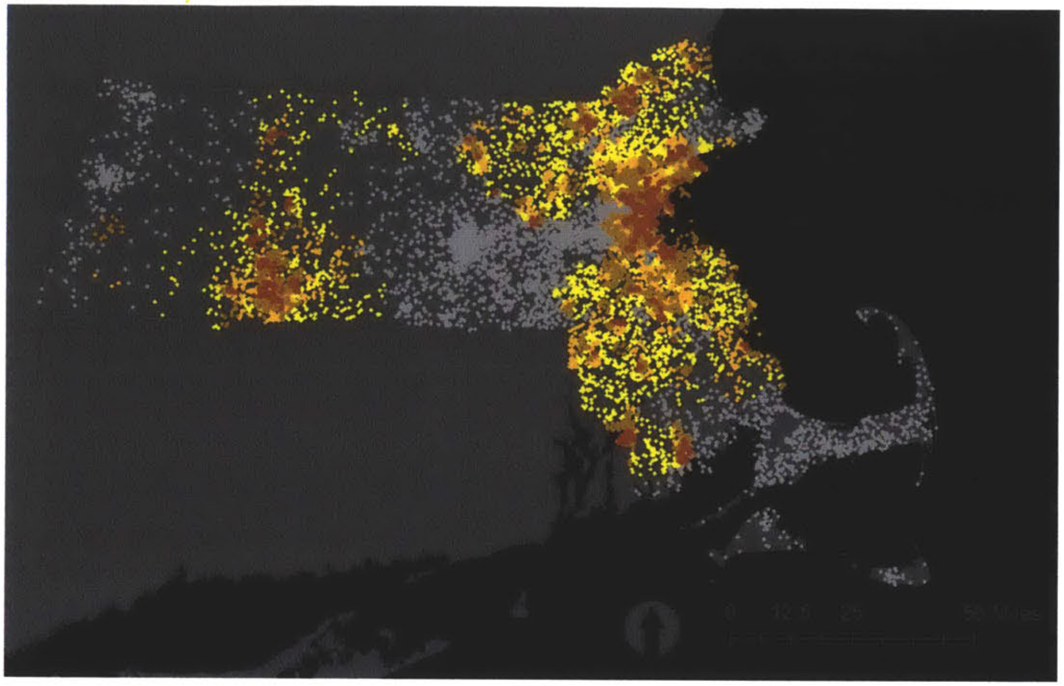
[3] 1 dot represents 500 people
[4] ibid.

Figure 24. Group 3: Dot Density Map[5] of Populations Exposed with Differing Vulnerability Indices



[5] 1 dot represents 500 people

Figure 25. Group 4: Dot Density Map[6] of Populations Exposed with Differing Vulnerability Indices



[6] ibid.