Chapter 3

Human Health and Climate Change in the Southeast USA

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Climate change is expected to have a broad impact on human health. This chapter discusses current and potential regional human health effects from climate change in seven major categories affecting the Southeast (SE): heat and cold; air quality and respiratory/airway diseases; storms, extreme weather, and sea-level rise; harmful algal blooms and marine toxins; vector-borne and zoonotic disease; water quality and quantity; and human migration/displacement and healthcare disruption. Health impacts in other areas, such as mental health and food security may also occur, but more research is needed to determine the potential effects in the SE.

Key Findings

- Higher ocean temperatures have already contributed to several outbreaks of harmful algal blooms and outbreaks of food-borne illnesses from marine toxins in shellfish.
- Rising air temperatures will worsen heat waves and increase levels of harmful pollutants such as ozone.
- Shifts in precipitation are expected to lead to more extreme precipitation events that can cause direct injury and other related health effects.
- Sea-level rise could impact human health by increasing storm surges and disrupting infrastructure and ecosystems.
- Vector-borne disease like dengue and malaria could be affected by rising temperatures and shifting precipitation patterns
- Water quality and quantity, which is already stressed, could be degraded

3.1 Climate Change and Human Health

Climate change is projected to affect human health in the Southeast (SE) USA in a variety of ways, both directly and indirectly. Increasing temperatures, shifts in weather patterns, and variations in sea level and water composition have the potential to exacerbate existing public health problems in the region while also leading to the introduction of novel diseases. The SE has a wide variety of ecosystems, ranging from the subtropical wetlands of the Everglades to the temperate forests of the Smoky Mountains, as well as diverse human development patterns including rural farmlands and large, dense cities. In addition, the SE experiences a wide range of weather events that can affect health and could be influenced by climate change. These factors complicate the assessment of climate-related health issues in the region.

Identifying the underlying health risks and vulnerabilities from climate change to the population of the SE is essential. By taking steps to reduce vulnerability to these events through improved monitoring, prediction, education, communication, engagement, and planning, the southeastern US can become more resilient to climate-related health impacts. Developing tools and products that translate weather and climate information into a form that is useful for public health can also help in managing and reducing vulnerability. There exists a dense network of weather stations in the SE, as well as a significant amount of health data from sources such as the North Carolina Disease

Event Tracking and Epidemiologic Collection Tool (NC DETECT), various Centers for Disease Control (CDC) tracking programs, and other federal, local, state, citizen-based and academic research programs. Opportunities to link disease surveillance systems with available climate and environmental data should be explored.

3.2 Heat and Cold

As a result of global climate change, global mean temperatures have been rising and are projected to continue rising. In the southeastern USA, average temperatures have already risen by 2°F since 1970, some areas more than others. Climate models project continued warming, with average annual temperatures rising by 4.5°F to as much as 9°F by the 2080s, depending on the emissions scenario used. Climate models project continued warming in all seasons across the SE and an increase in the rate of warming through the end of this century. Summer temperatures alone could rise by as much as 10.5°F on average (Karl et al. 2009). In addition, according to the 2000 National Climate Assessment the SE is expected to experience a greater increase in heat index than any other region of the country by 2100 (Burkett et al. 2001).

The negative relationship between increasing high temperatures and human health is well established, particularly the stresses on the cardiovascular, cerebral, and respiratory systems (Kovats and Hajat 2008, O'Neill and Ebi 2009). Extreme heat events cause more deaths annually in the US than all other extreme weather events combined (Luber 2008). In addition to the direct health effects from heat exposure, increasing temperatures can also exacerbate preexisting chronic conditions, like asthma, and contribute to formation of harmful air pollution and allergens (Portier et al. 2010). As with other USA regions, higher temperatures in the Southeast are expected to have an increasingly negative impact on human health.

Despite the increase in average temperatures in the SE over the past several decades, heat-related mortality overall has been decreasing. Improvements in health care and the prevalence of air-conditioning are likely the two main factors affecting the relationship between heat and mortality (Sheridan et al. 2009). Human biophysical acclimatization to higher temperatures in the region could also reduce mortality rates (Davis et al. 2003). However, the declining trend in heat-related mortality appeared to stabilize from the mid-1990s to the mid-2000s. Vulnerable and high-exposure populations such as the elderly, athletes, and outdoor laborers could be particularly at risk from increasing heat (Luber and McGeehin 2008), and population increase and demographic shifts in the SE could expand the vulnerable population in the future. For example, of 68 heat-related deaths among crop workers from 1992 to 2006 in the USA just under 30% occurred in the SE with 13 in North Carolina and 6 in Florida (MMWR 2008). Urban areas are also at risk, as several of the largest cities in the SE (Atlanta, Tampa, Miami, and New Orleans) have already seen significant increases in the number of hot days per year in which mean mortality is significantly above the summer baseline (Sheridan et al. 2009). Rising spring heat vulnerability was seen in Atlanta (Sheridan 2010). Increasing temperatures in the SE are projected to lead to increased ozone concentrations in the 19 largest urban areas in the region, causing an increase in mortality from exposure to harmful ozone levels and exacerbation of respiratory disease (Chang et al. 2010).

Expanding and improving the tracking and surveillance of heat-related illness can help to classify cases and allow planning for interventions to reduce the overall burden on the public health system. Improving education and communication, particularly among at-risk groups and communities, may best be accomplished through collaborative efforts between meteorologists and public health officials. Nationally, such efforts are underway between National Oceanic and Atmospheric Administration (NOAA) and the CDC, which recently signed a Memorandum of Understanding to help foster collaboration and connect climate data to health data. Moreover, designing and utilizing collaborative models for engaging at-risk citizens in building resilience to heat waves may prove an effective tool for reducing vulnerability and raising awareness to heat-related threats.

Rising temperatures could also affect food quality and security. Expanding population and land use changes have already reduced the existing land available for agriculture in the SE more rapidly than any other area of the country (Drummond and Loveland 2010). In addition, summer average temperatures are already at or above the optimal temperature range for major crops including corn, peanuts, soy, rice, and wheat (Hatfield et al., 2008). Moderate temperature increases may result in lower crop yields (Boote et al. 2005).

One benefit of increased temperatures is the potential for a reduction in cold-related deaths in the SE, although this has not been fully explored in the literature. Since the mid-1970s, the average number of freezing days in the SE has declined from four to seven days per year for much of the region, with some specific locations experiencing more and some fewer days (USGCRP 2009). However, the human health response to cold temperatures is much less pronounced than the response to high temperatures, making direct relationships between cold weather and mortality more difficult to predict (Laschewski and Jendritzky 2002).

3.3 Air Quality Effects on Respiratory and Airway Diseases

Climate changes impact air quality via several mechanisms, including increases in ozone production due to higher temperatures or a shift in cloud cover; changes in rates of precipitation scavenging, the process by which precipitation removes particulates from the atmosphere; shifts in vertical mixing due to changes in stability and wind speeds; and changes in the intensity or duration of tropical and extra-tropical cyclones and cold fronts which can remove pollutants. Impacts on air quality can also result from variation in vegetation type and amount, which affects biogenic emissions, and higher temperatures leading to higher fossil fuel consumption. In turn, atmospheric chemistry impacts climate, primarily via radiative effects of aerosols. The many feedbacks are not yet fully understood or simulated by current models (Denman et al. 2007). Changes in particulate matter, ozone, and other air pollutants have a direct impact on human respiratory and airway diseases.

Studies of climate change impacts on air quality in the southeastern USA have focused on ozone and small particulate matter ($PM_{2.5}$). In estimating future ozone and $PM_{2.5}$ levels, both air quality modeling simulations driven by downscaled global-climate model projections and empirical models linking future meteorological parameters with pollution levels have been reported in the literature. Although daily maximum

8-hour ozone levels in the SE have been generally estimated to rise in the 2040s and 2050s as compared to early 2000s, the magnitude of change varies among different studies, from less than 1 ppbv (Chang et al. 2010) to as much as 3 ppbv (Avise et al. 2009). The uncertainty in estimated daily maximum 8-hour ozone concentrations has been found to be approximately 2.5 ppbv in the SE (Liao et al. 2009). The resulting estimate of premature deaths that are attributable to climate change in the region ranges from a few dozen to a few hundred per year. Less research has been done on projected ozone-related morbidity, although a rise in outcomes such as hospital admissions due to respiratory illnesses, emergency room visits for asthma, and lost school days is expected (Tagaris et al. 2009). The relationships between pollutants and health outcomes are different under different air masses. Projections for North Carolina indicate moister air mass patterns and increased ozone, which likely would trigger asthma attacks and result in more emergency room visits (Hanna 2011).

There is less consensus in the estimated $PM_{2.5}$ concentration trends in the SE. A small increase of 1 mcg/m^3 has been reported in one study, as increased future emissions under the business-as-usual scenarios offset the air pollution reduction effects of increased precipitation and wet deposition (Avise et al. 2009). Another study projects a slight decrease of $PM_{2.5}$ levels by 2050, resulting in fewer cases of related premature mortality as well as morbidity outcomes (Tagaris et al. 2009). In addition, current air quality models such as Congestion Mitigation and Air Quality (CMAQ) can underestimate $PM_{2.5}$ by as much as 30% (Tagaris et al. 2007). Another study found that uncertainty in estimated $PM_{2.5}$ concentrations is moderate in the SE (< 1 mcg/m^3) (Liao et al. 2009).

Wildfires reduce air quality and therefore also affect human health. Projected temperature increases coupled with anticipated precipitation changes in the SE could lead to increased evapotranspiration and lower vegetation water content. Lightning, a frequent initiator of wildfires, is expected to increase (Wu et al. 2008). Together, these factors indicate an increasing risk of wildfires, which continues a recent trend (Ebi et al. 2008). Particulate matter (PM) emitted by wildfires poses a serious health risk and specifically increases asthma. Studies have demonstrated that PM is associated with increases in hospital admissions and occurrences of acute asthma exacerbations (Zanobetti and Schwartz 2006). In the Carolinas, peat bog wildfires pose a health hazard, and even brief exposure to smoke associated with these types of wildfires has been associated with negative respiratory and cardiovascular outcomes (Rappold et al. 2011).

Climate change can also affect human health through shifts in airborne allergens. Recent changes in both carbon dioxide concentrations and temperature may be responsible for the observed trend of the earlier onset of the spring pollen season in the USA (Confalonieri et al. 2007). It is reasonable to expect that this trend will continue, and that the incidence of allergies and other respiratory illnesses related to airborne pollens will continue to increase.

3.4 Storms, Extreme Weather, and Sea Level Rise

Climate change may increase the probability of extreme weather events such as heat waves, floods, drought, and the intensity of tropical cyclones in the SE. Greenough et al. (2001) and the IPCC note that extreme weather events will be more frequent, costly, and likely raise the morbidity and mortality rate across the USA. The country's aging

population will be more vulnerable to extreme heat events especially in cities where the urban heat island effect can raise temperatures by 2°F to 10°F (Luber and McGeehin 2008; IPCC 2007). In addition, by 2030, several southeastern states, such as Florida, North Carolina, and Georgia are projected to have some of the largest numbers of older Americans (Administration on Aging 2011).

Tropical cyclones that make landfall will also impact public health systems in the southeastern USA, especially in populated coastal areas. The incidence of longer-lived tropical cyclones in the North Atlantic is correlated with increased sea-surface temperatures consistent with a warming climate (Mann and Emanuel 2006). The destructive potential of tropical cyclones in the North Atlantic basin, based on longer storm lifetimes and greater storm intensities, has been increasing since the mid-1970s (Emmanuel 2005, Wu et al. 2008).

In the aftermath of Hurricanes Katrina and Rita in 2005, coastal and inland populations along the SE USA suffered from breakdowns of various societal and infrastructure systems including governance and public health systems. Storm surge, high winds and falling trees, and rising and receding floodwaters led directly to deaths and injuries and also impeded transportation and prevented many people from obtaining emergency medical services. The lack of potable water was a major concern, as people require water for hydration, food preparation, and washing. Raw sewage and industrial contaminated waters disrupted the water distribution system and became a major environmental and health issue (IOM 2007). Survivors showed a higher prevalence of serious mental illness (Kessler et al. 2006), and a study by the CDC seven weeks after Hurricane Katrina indicated that half of returning residents in Orleans and Jefferson Parishes had a possible need for mental health assistance while 33% had probable need for mental health assistance (MMWR 2006). The havoc that these storms wreaked is emblematic of the potential public health impacts from future powerful storms in the SE.

Sea level rise is another potential consequence of the Earth's warming. Changes in Mean Sea Level (MSL) are of major interest to public health in the northern Gulf of Mexico (nGOM) due to the large extent of coastal wetlands, productive fisheries, and large resident populations. The major impacts from MSL rise cited in the IPCC 2007 report are inundation, flood and storm damage, erosion, saltwater intrusion, rising water tables, impeded drainage, and wetland loss, all of which could have an impact on human health. Barrier islands and other low lying areas are subject to increased frequency and levels of flooding, which has human health implications from direct injury and disruption of emergency response. MSL rise and coastal erosion may affect nearshore ecosystems including seagrasses and oyster reefs, which degrade habitats essential for commercial fisheries, possibly leading to shellfish contamination (Hagen et al. 2011, also see Chapter 11). Adaptation strategies that protect critical infrastructure from sea level rise have the potential to protect public health by supporting emergency response during flood events and protecting marine food supplies.

3.5 Harmful Algal Blooms and Marine Toxins

Harmful algal blooms (HABs) are toxin-producing blooms of algae including cyanobacteria that can endanger human health (Landsberg 2002, Backer et al. 2008). HABs have caused mass mortalities of fish and marine mammals in the ocean, killed domestic

animals on land, and sickened people through exposure to the toxins by consumption of contaminated seafood or through recreational exposure (Backer and McGillicuddy 2006). In the eastern USA, the major toxin producers are dinoflagellates and cyanobacteria. These organisms have life cycles that can be influenced by climatic patterns; changes in climate may increase the effects of HABs and consequently increase concern for food safety and public health (Tirado et al. 2010).

A variety of climate changes can be expected to cause changes in the frequency, distribution, and intensity of toxic algal blooms in inland and coastal waters (see Table 3.1). These include warmer temperatures and changes in the timing of lake warming, changes in the duration of calm winds, as well as changes in the intensity and duration of hurricanes. Over the past decade significant strides have been made in understanding how climate affects HABs (Moore et al. 2008, Tester et al. 2010, Hallegraeff 2010), which should improve predictions of these blooms in the future.

Table 3.1 Summary of Potential Climate Impacts on Marine Toxins in the Southeast.

Organism	Location	Trend	Citation(s)
Cylindrospermopsis raciborskii	Established in Florida in the 1990s	Moving up the Eastern seaboard; early onset of warm season encourages growth	Wiedner et al. 2007
Karenia brevis	Florida	Northward movement to North Carolina; appearance in Mississippi and Louisiana	Tester et al. 1991, Maier Brown et al. 2006
Dinophysis	Gulf of Mexico	First appearance in the US occurred in 2008	Campbell et al. 2010
Pyrodinium sp	Florida	Established in Florida from the mid-1990s	Landsberg et al. 2006
Gambierdiscus sp	South Carolina, Texas, Louisiana	First appearances in the US occurred in the 2000s; northward movement observed	Villareal et al. 2007, Litaker et al. 2010

In the SE and Caribbean the most common coastal hazards from HABs are ciguatera fish poisoning (CFP) and neurotoxic shellfish poisoning (NSP), although potential risks of diarrhetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) exist (Landsberg 2002). CFP results from eating fish carrying ciguatoxin, a neurotoxin produced by species of the tropical dinoflagellate *Gambierdiscus*. With the exception

of scombroid fish poisoning (associated with mishandling of fish after harvest), ciguatoxin is the most common foodborne illness associated with fish, affecting an estimated 50,000 to 500,000 people per year globally. In the USA, CFP illness is concentrated in the Virgin Islands, Puerto Rico, south Florida, and Hawaii. A subset of patients develops chronic symptoms, which may be associated with long-term disability (Litaker et al. 2010). NSP results from brevetoxin, produced by the dinoflagellate *Karenia brevis* and some related species. *K. brevis* produces the well-known "red tide" in Florida. Brevetoxin is unusual in that it can become aerosolized, leading to respiratory distress in humans. During a bloom, hospital admissions for respiratory illness increase, and asthmatics are especially at risk (Kirkpatrick et al. 2006, Fleming et al. 2009). An economic byproduct of red tide is changes in tourism plans that can lead to millions of dollars in losses to coastal communities (Larkin and Adams 2007; see Chapter 5).

Cyanobacteria also produce a variety of health risks (Backer 2002) including the hepatotoxin *Microcystin*. In addition, cyanobacteria produce several other toxins that pose health risks. Dermatitis as a result of recreational exposure is an additional risk to humans. *Cylindrospermopsis raciborskii* is a cyanobacterium of subtropical origin that appeared in Florida in the early 1990s and has established itself in the eastern USA and has also bloomed in the Midwest. The cause of the spread is uncertain but earlier onset of the warm season favors its growth (Wiedner et al. 2007). Changes in climate that affect the timing of the warm season in these areas may favor development of *Cylindrospermopsis* blooms.

As climate change affects water temperature and rainfall, shifts in phytoplankton populations are expected (Moore et al. 2008; Hallegraeff 2010). As a particular water body changes with climate, a niche shift is likely to provide the opportunity for new species to populate. Changes in rainfall and the subsequent nutrient shifts likely will alter the dynamics of the population. In October 1987, *Karenia brevis* (Florida "red tide") was transported in the Gulf Stream to North Carolina, resulting in closures of shellfisheries in both Carolinas from October until late winter 1988 (Tester et al. 1991). *Dinophysis*, which has not been a problem in the USA, appeared in the Gulf of Mexico in March 2008, causing a closure of shellfish beds, as well as a recall of oysters. Blooms of tropical *Pyrodinium* sp. have appeared in Florida in the last decade, and have caused PSP through consumption of fish containing saxitoxin (Landsberg et al. 2006).

Climate change may lead to the expansion of ciguatera fish poisoning (CFP) in tropical areas as well as more temperate zones. While higher sea surface temperatures are associated with higher rates of CFP (Hales et al. 1999, Tester et al. 2010), studies also have suggested that there may be a maximum temperature at which the toxin responsible for CFP can grow, with risk declining above this temperature (Leewellyn 2010). The preferred substrate of *Gambierdiscus* is macroalgae, which may spread as a result of coral bleaching (Tester et al. 2010). In the Caribbean, longer duration of warm temperatures favors development of *Gambierdiscus* spp. potentially allowing ciguatera to bio-accumulate in reef fish over a longer period of time (Tester et al. 2010). This will also cause a decrease in the amount of time available for the toxin to depurate. In the past decade, CFP has been documented from fish caught in South Carolina and in the Flower Garden Banks National Marine Sanctuary on the Texas/Louisiana border. These observations suggest that the disease is moving northward, possibly in association with increasing sea surface temperatures (Villareal et al. 2007, Litaker et al. 2010).

The frequency and intensity of other events, such as hurricanes, may result from climate change and may play a role in the spreading of blooms. The first documented *K. brevis* bloom in Mississippi and Louisiana occurred in 1996 when Tropical Storm Josephine transported a Florida bloom westward (Brown et al. 2006). Hurricane Katrina in 2005 transported a *K. brevis* bloom from southwest Florida to the north Florida coast (Carlson and Clarke 2008). While the full effect of hurricanes on HABs is not clear, these storms have contributed to the spread or relocation of blooms in the past and it is likely this trend will continue in the future.

3.6 Vector-borne and Zoonotic Disease

The subtropical climate in Florida and parts of the SE is attractive to mosquitoes, including vectors for the most important mosquito-borne diseases. These diseases include malaria, vectored by *Anopheles* sp. mosquitoes; and yellow fever, chikungunya, and dengue fever vectored by *Aedes aegypti* and *Aedes albopictus*. Outbreaks of dengue occurred regularly in Florida before the 1950s, when mosquito control efforts were implemented across the state. The vector, *A. aegypti*, also called the Yellow Fever mosquito, lives in close proximity to people, in and around homes. Mosquitoes prefer warm environments with high humidity. Modern homes with air conditioning and screens help interrupt transmission by separating the vectors from susceptible hosts. Local transmission of dengue and malaria in the southeastern USA is now rare, partially due to the actions of the Centers for Disease Control and Prevention, which was created to help with the control and prevention of malaria and related diseases. However, as the 2003 malaria outbreak in West Palm Beach (MMWR 2004) and the 2009 and 2010 dengue fever outbreak in Key West (2010b) showed that disease transmission is still possible when pathogens are introduced by travelers.

How climate change will impact vector-borne and zoonotic disease transmission in the southeastern USA is still uncertain. Vector-borne disease transmission cycles are complex and influenced by many factors. An increase in temperature is likely to shorten the development time of immature vectors to adults and also shorten the extrinsic incubation period of the pathogen in an infected vector (Watts et al. 1987). However, vectors also require access to water to breed, vegetation and humidity to disperse, and susceptible vertebrate hosts to propagate the disease transmission cycle. Regardless of the complexity of these transmission cycles, it is important to note that with climate change, it is likely the SE tropical wet-dry climate zone will expand. This is the climate zone where the most intense vector borne disease transmission occurs around the world. It is possible that the expansion of the wet-dry tropical climate zone in the SE USA will result in more favorable ecologic conditions for vector-borne disease transmission; however, lifestyle and socioeconomic patterns have a great effect on limiting these diseases in the region.

The greatest climate change related vector-borne disease concerns are associated with the expansion of habitats or accessible hosts for the mosquito *A. aegypti*. The human population in the SE is growing fast and the demand for drinking and irrigation water is increasing. *A. aegypti* is known to readily adapt to urban environments with high host densities. As energy prices increase, the cost of running air-conditioning may result in increased disease transmission due to higher prevalence of open windows. In

addition, climate change is predicted to increase the severity of tropical storms and hurricanes. During the many months required to repair homes damaged by such storms, residents are potentially vulnerable to mosquitos. In addition, debris from the storms creates mosquito-breeding habitats, potentially increasing mosquito populations.

Zoonotic disease transmission is dependent on contact between infected animals and susceptible human hosts, and it is possible that any climate-associated ecological changes that facilitate such contact will result in an increased risk for zoonotic diseases. For example, the anticipated water shortages during periods of drought may facilitate zoonotic disease transmission by attracting raccoons, a rabies vector species, and other wildlife to human water supplies. By 2055, changing temperature and precipitation patterns could shift the zoonotic disease tularemia northward, resulting in reduced infections in the central-south area of the USA (Nakazawa et al. 2007).

3.7 Water Quality and Quantity

Worldwide, climate change is expected to increase diarrheal incidence by 10% by 2030 (Shuman et al. 2010), much of which will be associated with the waterborne disease transmission route. In the USA, while widely underreported (Blackburn et al. 2004), waterborne diseases continue to cause significant morbidity; exposure patterns and illness rates may change alongside climate and weather patterns (Semenza et al. 2012).

Human exposure to climate-sensitive pathogens occurs by ingestion of water intended for drinking; incidental ingestion during swimming; or direct contact with eyes, ears, or open wounds. Bivalve shellfish, such as oysters, also can concentrate pathogens in water or pathogens in irrigation water can be deposited on produce; both food sources can then serve as vehicles for water-associated bacteria and viruses. Pathogens of concern for waterborne exposure could be either enteric and transmitted by the fecal-oral route (enteric viruses, bacteria and protozoa) or can occur naturally in aquatic systems (bacteria and protozoa), where they could cause a range of diseases. Climate can act on these pathogens directly by influencing growth, survival, persistence, transmission, or virulence. Changing climate or environments could alter or facilitate transmission of the pathogens or affect the ecology and/or habitat of zoonotic reservoirs.

Climatological drivers, especially those affecting the hydrologic cycle, can influence how contaminants are introduced, transported, and processed in coastal ecosystems. Climate change in the SE has affected the regional hydrologic cycle (Portmann et al. 2009). In particular, there has been a significant shift in summer precipitation patterns over the SE, with a move toward higher variability in recent years (Wang et al. 2008). Exceptionally dry and wet summers will be more likely during the 21st century (Li et al. 2011). Recent summer precipitation patterns show multiple shifts from drought to extreme precipitation. This severe combination of more frequent drought with episodes of intense rainfall alters overland and groundwater flow, changing mobilization patterns of inorganic and organic nutrients and contaminants (Boxall et al. 2009). There is also current evidence for the role of climate change and variability on water quality and waterborne disease in the SE including (1) expansion in temporal (seasonal) ranges of certain disease and pathogens related to moderate changes in temperature, (2) increased loading of enteric pathogens due to intense precipitation events, and (3) periodic exposure to multiple pathogens during hurricanes and extreme events.

There is a commonly noted correlation between general diarrheal disease (irrespective of agent) and ambient temperatures. This phenomenon has been documented in both the northern and southern hemispheres and across geographical areas (Hall et al. 2005, Singh et al. 2001). Infections with *Salmonella enterica* serovars continue to be among the top sources of foodborne disease in the USA, and the SE reports the highest rates in the nation (CDC 2010a). Worldwide, including the USA, *Salmonella* cases peak with the highest annual temperatures (D'Souza et al. 2004, Kovats et al. 2004, Fleury et al. 2006, Naumova et al. 2006), although the specific mechanism for this trend is not clear. One study in southern Georgia showed that maximum waterborne prevalence of *Salmonella* and diversity of serovars, especially those associated with human clinical cases, are most common in summer months (Haley et al. 2009). Increased risk of waterborne exposure may be driving many of the sporadic cases of *Salmonella* infections that are currently driving regional and national trends in increasing disease incidence (Clarkson et al. 2009).

Naturally occurring pathogens, including the marine bacteria *Vibrio* spp., are directly associated with warm temperatures. While the genus is commonly found in coastal waters worldwide, four species are commonly associated with human disease: *V. parahaemolyticus*, *V. vulnificus*, *V. cholerae* non-O1 and *V. alginolyticus*. *Vibrio* spp. are the most common bacteria associated with shellfish disease in the USA and a common cause of wound, eye, and ear infections. *Vibrio* illnesses are common in the coastal states of the SE, especially along the Gulf coast, where most cases of *V. vulnificus* arise (Yoder et al. 2008).

Pathogenic *Vibrio* spp. are well adapted to coastal waters and proliferate at warm temperatures, particularly above 15°C (Martinez-Urtaza et al. 2010), and human infections are more frequently observed in warm climates (Dechet et al. 2008, Iwamoto et al. 2010, Weis et al. 2011). Reported human cases also peak during summer months, corresponding with warm temperatures and increased human exposures through seafood and recreational water use (Dechet et al. 2008, Dziuban et al. 2006, Iwamoto et al. 2010, Yoder et al. 2008). Additionally, in the USA, human reports from Gulf Coast states and southeastern Atlantic states include a greater overall diversity of *Vibrio* spp. associated with infections (Dechet et al. 2008). Recent analyses on *Vibrio* infections associated with consumption of Gulf Coast shellfish indicates that cases are expanding temporally, with cases now frequently reported in April, one month earlier and in November, one month later than traditionally observed (Martinez-Urtaza et al. 2010). This trend is associated with an increase in the number of days in each month when water temperature is greater than 20°C. From the decade between 1997 and 2007 compared to the decade between 1987 and 1997, there were water temperatures reaching more than 20°C for five days in April with a 300% increase in the number of *V. vulnificus* illnesses (Martinez-Urtaza et al. 2010). Across the USA, rates of *Vibrio* spp. infections have grown by more than 115% since 1996 (CDC 2011).

Changes in precipitation leading to increased flooding may have the greatest potential impact on food and waterborne disease, especially those associated with the fecal-oral route. A retrospective analysis of waterborne outbreaks associated with drinking water in the USA between 1948 and 1994 revealed that 51% of outbreaks occurred following a daily precipitation event in the 90th percentile and 68% occurred when precipitation levels reached the 80th percentile (Curriero et al. 2001). Waterborne patho-

gens associated with point and nonpoint sources of pollution include *Cryptosporidium* spp., *Giardia* spp., *Salmonella* spp., *Campylobacter* spp., and a range of enteric viruses, such as noroviruses, hepatitis A viruses, and enteric viruses.

High levels of precipitation may cause the spread of pathogens in a number of ways: overloading of wastewater treatment plants leading to diversion of waste water to combined sewer overflows, increased runoff of pesticides and other contaminants from agricultural or urban lands, or the failure of septic systems. Such events may expose people to significant quantities of enteric pathogens as has been documented with storm events in the SE (Lipp et al. 2001a, Shehane et al. 2005, Vereen et al. 2007, Stumpf et al. 2010, Parker et al. 2010).

The specific effects of climate variability on water quality in the SE have been determined using El Niño-Southern Oscillation (ENSO) events as a model for interannual variability in retrospective studies. Tidally influenced rivers in the SE respond to increased precipitation and streamflow associated with El Niño events with significantly higher levels of fecal contamination that are measured using fecal coliform bacteria (Lipp et al. 2001b, Chigbu et al. 2004). Moreover, specific enteric pathogens, such as enteric viruses, are also more likely to occur with high precipitation and streamflow associated with El Niño winters (Lipp et al. 2001a).

Water quality is also impaired during extreme events, specifically hurricanes, which are projected to increase in strength under various climate change scenarios. Hurricanes associated with large storm surges and tidal inundation may increase exposure for *Vibrio* spp. in affected populations as was seen in Gulf Coast states following the 2005 hurricanes, Katrina and Rita. The incidence of *Vibrio* spp. infection increased relative to previous periods, with 22 wound infections and five deaths in slightly more than a one-month period (Heilpern 2005). Flooding can also result in contamination from fecal sources and associated increase in enteric illnesses. In 1999, Hurricane Floyd flooded much of eastern North Carolina, including farm and livestock operations. This massive flooding event resulted in high levels of fecal contamination (Bales et al. 2000). The number of people seeking treatment for gastrointestinal illness doubled (Setzer and Domino 2004).

3.8 Human Migration and Displacement and Healthcare Disruption

Past disasters have identified problems associated with medical surge capacities during disaster events. Not only are the medical services within a disaster area often overtaxed (Franco et al. 2006), but, in many instances populations evacuating from impact zones to safe areas can overwhelm medical services in the safe zone (Sheppa et al. 1993, Gagnon et al. 2005, Gavagan et al. 2006, Stratton and Tyler 2006, Allen et al. 2007). Figure 3.1 shows the displacement pattern of Mississippians to other parts of the nation after Hurricane Katrina. These disaster diaspora populations often need more than food, water, and shelter during the transition from victims to survivors. One of the least understood aspects of this additional need is related to medical surge and the need to create accurate plans for the accommodation of increased patient volumes both inside and outside of the disaster impact zone (Hick et al. 2004, Bonnett et al. 2006, Barbisch

and Koeing 2008). With climate change likely to increase extreme weather events in the SE, including storm intensity, increased health implications associated with this type of migration will be expected to increase in the future. Mental health impacts could result from traumatic stress and deterioration of community wellbeing (Berry at al. 2010), especially for the disadvantaged communities in the SE (Wilson et al. 2010). The severity of mental health impacts such as anxiety and emotional stress following an extreme climate event will depend on the resiliency and capacity of the public health and emergency response system, both during and following the event (Portier et al. 2010).

Figure 3.1 Disaster diaspora populations from Mississippi by evacuation location.

3.9 References

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