CHAPTER 4

Climate Change Impacts on Human Health

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Climate change poses major challenges to human society and to Earth systems, influencing the functioning of many ecosystems and thereby affecting human health. Many climate change/variability- and extreme weather-associated events, such as sea level rise, hurricanes, and storm surge, as well as other weather extremes, including excessive precipitation and heatwaves, have direct and/or indirect impacts on human health. These impacts include death/injury, cardiovascular and respiratory diseases, environmentally-mediated infectious diseases, and mental health, among others. Due to its unique geography, Florida is particularly vulnerable to these environmental impacts, which have important health implications for the state's more than 20 million residents. In this chapter, we review the health impacts of climate change and associated weather events, with an emphasis on those relevant to Florida, and environmental hazards, including hurricanes and storms, lightning, sea level rise, excessive precipitation, extreme heat, and drought. There is clear evidence for significant climate-sensitive hazards and human health impacts in the state, despite uncertainties associated with the assessment of some effects. To address health impacts and challenges, policies focused on mitigation and adaptation strategies, health surveillance, and research that could close knowledge gaps on human exposures to the climate-sensitive hazards and health impacts are needed.

Key Messages

- Florida is highly vulnerable to climate-sensitive hazards (e.g. sea level rise, heat waves, storm surge, and hurricanes), which have a wide range of human health effects.
- The health effects can be direct, such as storm/temperature related illnesses, injuries, and deaths; or indirect, such as waterborne, food-borne, and vector-borne diseases; or take social and economic pathways, such as stress and mental illness.
- The health effects exhibit substantial regional disparities across the state.
- Policies focused on health surveillance and research on knowledge gaps between human exposure to the hazards and health effects are much needed.

Keywords

Climate change; Environmental hazards; Human health; Florida

Introduction

Climate change is well-characterized at the global level using metrics such as the global mean temperature and sea level. But the manifestations of global climate change and variability occur at varying geographical scales, causing a variety of weather events, such as excessive rainfall, drought, severe storm/flooding, sea level rise, and heat waves (Field et al. 2014), all of which are likely to have direct and/or indirect human health impacts (McMichael and Haines 1997; Colwell et al. 1998; Frumkin et al. 2008). Indeed, there is clear and increasing evidence that many health outcomes (most adverse) exhibit high sensitivities to these varying weather events. The interface between the climate change-associated weather events and human health exhibits a complex web of relationships involving both natural and social environments through direct or indirect impact pathways, social institutional disruption, or a combinations of these things (Fig. 4.1). Globally, substantial disease burdens are attributable to hazards that are associated with climate change and related weather events. According to the World Health Organization's 2008 estimate, climate change-associated hazards were responsible for more than 150,000 deaths and 5,517,000 disability-adjusted life years, which were highly likely to be underestimated as the estimates were only based on selected risk factors and illnesses associated with climate change and related weather events (WHO 2008). The actual disease burden might be greater and the adverse health impacts are likely to increase in the years to come, as the Intergovernmental Panel on Climate Change (IPCC) and US Global Change Research Program have clearly indicated that the accelerated changing climate poses a substantial threat to global human health and the risk will continue to become severe if no remediation action is taken (Field et al. 2014; Balbus et al. 2016).

Due to its unique geography, Florida is highly vulnerable to a variety of hazards associated with climate change and variability, and related weather events. Sea level rise, hurricane and storm surge, excessive precipitation, and heatwaves all pose threats to Florida's agriculture, ecosystems, tourism, and public health. For example, Florida has experienced a greater number of hurricane landfalls than other states in the country (Knight and Davis 2009), and more intense hurricanes are expected in the future (Knutson et al. 2013). In addition, rising sea levels are influencing and expected to continue to have significant impacts on communities and residents along Florida's coastal areas, particularly in the southern part of the state, making Floridians exceptionally vulnerable to these environmental hazards (Elsner et al. 2008).

This chapter is organized into sections addressing impact pathways and specific environmental hazards of particular concern in Florida (Fig. 4.1). For direct impacts, we focus on extreme heat, flooding, storms and lightning, and sea level rise. For indirect impacts on public health, we focus on water, food, and vector-borne diseases. And lastly, we conclude with our discussion of impact pathways through social disruption on mental and community health impact associated with climate change and related weather events. Throughout this chapter, health impacts and implications, particularly those pertinent to Florida, are reviewed primarily based on the *Building Resilience Against Climate Effects* (BRACE) project reports from the Florida Department of Health (FDH) (FDH 2015b, a) and other relevant publications.

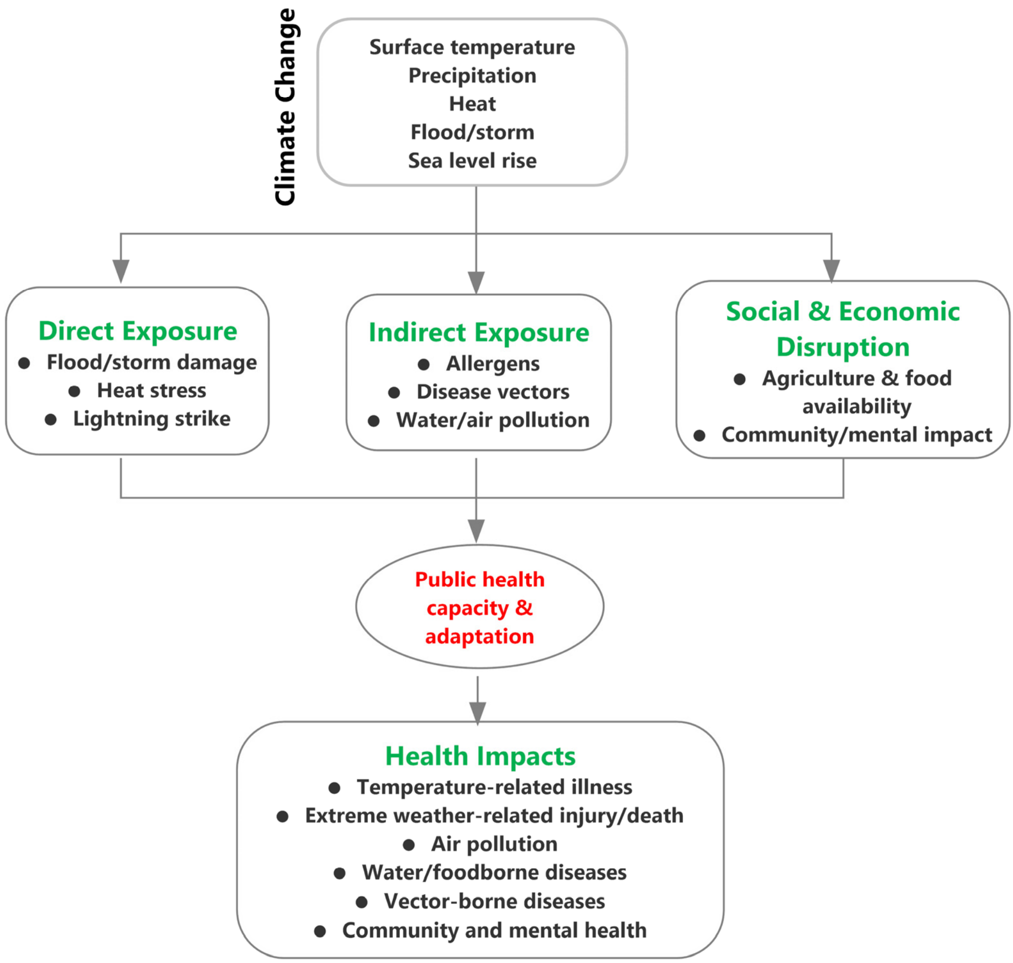

Figure 4.1. Impact pathways by which climate change and variability and related weather events affect human health.

Direct Impact Pathways – Environmental Hazards and Human Health

A number of human health impacts come from direct exposure to environmental hazards associated with climate change and related weather events. Among those of particular concern in Florida are extreme heat, flooding, storms and lightning, and sea level rise.

Extreme Heat and Health Impacts

Extreme climate and weather events (e.g., heat, cold, storms, and floods) are expected to occur more frequently worldwide due to climate change. These extreme events, such as heatwaves and cold spells (e.g. frequent very hot days and possibly fewer very cold days), have a direct impact on human health by compromising the body's ability to regulate its internal temperature. Increased human morbidity and mortality have been associated with extreme temperatures, both hot and cold, and documented in both developing and developed countries worldwide (Center for Disease Control and Prevention 1994; Keatinge et al. 2000a; Keatinge et al. 2000b; Basu and Samet 2002; Medina-Ramon et al. 2006; Kovats and Hajat 2008; Bandyopadhyay et al. 2012). The mechanistic effects of extreme temperature on death and illness are briefly summarized below (Sarofim et al. 2016):

- Extreme heat may induce heat cramps, heat exhaustion, heatstroke, and hyperthermia.
- Extreme cold may induce hypothermia and frostbite.
- Extreme heat/cold may exacerbate chronic conditions related to cardiovascular disease, respiratory disease, cerebrovascular disease, and diabetes-related illnesses.
- Extended exposure to high temperatures may induce increased hospital admissions for cardiovascular, kidney, and respiratory disorders.
- Extreme heat may induce or exacerbate mental health and behavioral disorders.

A number of studies have reported associations between high temperatures and human deaths or illnesses around the world. For example, a large number of heat-related deaths have been reported in the United States (Center for Disease Control and Prevention 1994; Curriero et al. 2002; Hoshiko et al. 2010), Europe (Keatinge et al. 2000a; Keatinge et al. 2000b; Huynen et al. 2001), and Asia (Qian et al. 2008; Chung et al. 2009). A recent study by Berko et al. examined deaths attributed to extreme weather events from 2006 to 2010 in the United States and found that each year about 2,000 U.S. residents died from weather-related causes, and among those 31% died due to exposure to excessive heat, heat stroke, and/or sun stroke (Berko et al. 2014). Mounting evidence has suggested that substantial increases in mortality from respiratory and cardiovascular diseases, in particular among the elderly and youth, are associated with high temperatures in the United States (Basu and Samet 2002; Medina-Ramon et al. 2006; Kovats and Hajat 2008). During the 2006 California heat wave, 16,166 excess emergency department visits and 1,182 excess hospitalizations were reported statewide. This included a significant increase in emergency department visits for acute renal failure, cardiovascular diseases, and diabetes (Knowlton et al. 2009). The association between heat and respiratory diseases has also been reported in many studies. In New York state, a significant number of respiratory hospitalizations were attributable to excessive heat, and a projection suggested that excess respiratory admissions in the state due to extreme heat will be two to six times higher in 2080–2099 than what was seen in 1991–2004 (Lin et al. 2012). In another study conducted in Greater London, UK, an analysis of historical data suggested that heat-related increases in emergency admissions for respiratory and renal diseases had been observed in children under five, and for respiratory disease in the 75+ age group (Kovats et al. 2004).

Extreme Heat and Public Health in Florida

Florida has a warm subtropical and tropical climate. Due to continuous summer heat and extreme weather events, temperatures around the state can reach levels potentially harmful to human health. Through analyses of historical data (for the periods 1895–2009 and 1970–2009), a significant trend in Florida's mean temperature has been found (Martinez et al. 2012). The average summer temperature (June–August) has been showing an overall increasing trend, particularly after the 1980s, which shows a greater upward trend (FDH 2015a), likely due to a variety of factors ranging from rapid urban development (Martinez et al. 2012; FDH 2015a) to climate change (Ji et al. 2014). Within the state, substantial spatial heterogeneities in mean, minimum, and maximum temperature have been reported (Martinez et al. 2012). For example, the distribution of annual mean number of days with a maximum temperature greater than or equal to 95 °F and greater than or equal to 75 °F showed that more days with hottest daytime temperatures occurred in the northern and interior portions of the state (FDH 2015a).

Using statewide information on specific health outcome-related emergency department visits that occurred May to October from 2005–2012, the BRACE project examined the effects of daily maximum temperature or daily maximum heat index on emergency department visits through a two-stage analysis—the first stage involved the analysis on regional (National Weather Service regions) scales using the Poisson regression model; the second stage used a meta-analysis technique to integrate regional estimates into a statewide estimate (FDH 2015a). Rate ratios, based on the comparison between the exposure (e.g., hotter days) and the reference (e.g. 88 °F for temperature and 94 °F for heat index), were used to compare emergency department visits for specific health conditions (FDH 2015a).

a) *Heat and heat-related illness*. A strong association between heat-related illness and heat exposure was observed; the significant increase in emergency department visit rates for heat-related illness was associated with increasing temperatures and a strong dose-response relationship across all regions in Florida was found (FDH 2015a).
b) *Heat and cardiovascular disease*. Two types of cardiovascular disease were considered—myocardial infarction and ischemic stroke. No statistically significant association was found between temperature and ischemic stroke at the state level; however, significant regional variations were identified. For example, the Tampa region showed a significant positive association between heat index (above the reference level at 94 °F) and stroke (FDH 2015a). Furthermore, a positive, statistically significant relationship was observed between myocardial infarction and heat index despite remarkable geographical variations (FDH 2015a).

c) *Heat and respiratory disease*. Overall, increases in the number of emergency department visits for asthma were associated with higher temperatures. Although no significant association was found at the state level between temperature and emergency department visits for asthma, the regional analysis suggested that all regions except Tallahassee showed a statistically significant positive association between temperature and asthma (FDH 2015a).

Flooding, Storms, Lightning, and Sea Level Rise

Excessive precipitation, hurricanes, coastal storms, sea level rise, and thunderstorm-related lightning, which are all typically accompanied by coastal and inland flooding, have the potential for substantial direct human health impacts (e.g. injury and death, maternal and child health, and mental health issues). Natural disasters related to flooding and storms are a significant cause of mortality and morbidity. For example, according to the International Federation of Red Cross and Red Crescent Societies (IFRCRCS), more than 3,448 climatic, hydrological and meteorological disasters (including 1,751 major floods and 988 storms) resulting in 339,710 deaths (59,092 and 177,685 deaths specifically tied to flooding and storms) were reported worldwide between 2005 and 2014 (IFRCRCS 2015). Lightning strike is the second leading cause of weather-related mortality at the global scale, with an estimated 0.2-1.7 deaths per million people, and those who survive lightning strikes often suffer from significant injuries (Aslar et al. 2001; Ritenour et al. 2008). The magnitude and impacts of these extreme weather events, their severity, and the extent of the effects are influenced by many different factors. For example, short- and long-term averages and variability of weather conditions and physical impacts of associated extreme events, as well as social environmental factors (e.g. infrastructure, social and individual vulnerability), are considered important (Bouma et al. 1997, Kovats 2000, Kovats et al. 2003, Miranda 2004). For projections of future flooding under different climate change scenarios, climate models have consistently suggested that episodes of severe flooding may become more frequent in inland river systems including flood plains (Christensen and Christensen 2003, Booij 2005), urban and coastal environments in various parts of the world (Schreider et al. 2000; Douglas et al. 2008; Kirshen et al. 2008; Thompson et al. 2009, Diez et al. 2011; Lyle and Mills 2016). Meanwhile, climate models also predict positive correlations between lightning and global temperatures, suggesting the likelihood of a greater number of and more severe lightning episodes (Price and Rind 1994; Reeve and Toumi 1999; Kochtubajda et al. 2006). These episodes are expected to increase the risk of extreme environmental hazards and adverse public health impacts.

a) *Natural disasters in Florida*. Due to its geography (extensive coastline and a peninsular shape) and its tropical/subtropical climate, Florida is particularly vulnerable to tropical storms, hurricanes, and lightning strikes. Historically the occurrence of hurricanes in the US has been clustered in Florida and along the Atlantic coastline (Ellis et al. 2015). A total of 67 known Florida hurricanes have occurred over the 108-year period (1900-2007) with four different hurricanes occurring in one year (2004) in Florida. The climate change model suggests a 46% chance that Florida will be hit by at least one hurricane each year in the future (Malmstadt et al. 2009), and recent experience seems to support this. Fig. 4.2 illustrates the distribution of average return time of hurricane landfalls and populations along the coastal areas of Florida, showing spatial heterogeneities in vulnerability to hurricanes.

b) *Public health impacts*. Key direct public health impacts associated with extreme weather events include injury and death due to trauma, drowning, destructive forces of wind, collapsed building and trees, and lightning strike and carbon monoxide poisoning related to power outages. Historically, Florida experienced significantly higher mortality in the early 20th century; approximately 3,000 deaths were attributed to extreme weather-related events (Winsberg 2003) and the largest number of deaths due to lightning strike in the US were reported during this time (Duclos et al. 1990; Ritenour et al. 2008). During 2004 and 2005, eight hurricanes hit Florida resulting in 213 deaths, over half of which were caused by trauma, followed by drowning, other injury, electrocution, and carbon monoxide poisoning (Ragan et al. 2008). Injury is common cause of hurricane-related morbidity and mortality. For example, in the aftermath of Hurricane Katrina between September 8 and October 14, 2005, 7,543 non-fatal injuries among residents and relief workers were recorded in the surveillance system (Sullivent et al. 2006). During a 2006 flood event in El Paso County in Texas, 43% of individuals (out of 475 surveyed) were reported having physical health issues related to the flooding episode (Collins et al. 2013).

c) *Injury*. The BRACE study compared injury-related emergency department visits and hospitalizations during impact periods (periods covering tropical cyclone landfall) vs. control periods (periods with no such impact) between 2004 and 2012. The study found that emergency department visit and hospitalization rates were significantly higher during the impact periods, with a rate ratio of 1.03 (95% confidence interval (CI): 1.02, 1.05) for the emergency department visit rate and 1.4 (95% CI: 1.02, 1.05) for the hospitalization rate. The most common types of injuries during the impact periods included falls, being struck by an object, being cut or pierced, and motor vehicle transport accidents (FDH 2015b).

d) *Carbon monoxide poisoning*. Carbon monoxide (CO) is a colorless, odorless, poisonous gas that can be harmful when inhaled in a large amount. Inhaled CO enters the blood stream and reduces the delivery of oxygen to the body's critical organs, such as the heart and brain. The gas is primarily generated through incomplete combustion. The greatest sources of CO outdoors are usually related to motor vehicles, machinery that burn fossil fuels. Indoors, some major sources include unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves. Exposure to CO may cause weakness, headache, dizziness, nausea, shortness of breath, confusion, and even death at very high concentration levels, which is more likely in indoor environments. A recent systematic review of the health impacts of power outages due to extreme events indicated that CO poisoning is an important health concern (Klinger et al. 2014). In Florida, the BRACE study reported that during the study period 2004–2012, the rate of CO exposure calls during impact periods was 6.59 times (95% CI: 4.48, 9.7) the rate of CO exposure calls to poison control centers during the control periods. The study also found the rate of CO-poisoning related emergency department visits was significantly higher for the impact periods than during the control periods with the rate ratio 3.44 (95% CI: 2.07, 5.72). Finally, the BRACE study revealed that rates of CO poisoning-related hospitalizations were also significantly higher during the impact periods with the rate ratio 4.0 (95% CI: 2.9, 5.51) (FDH 2015b).

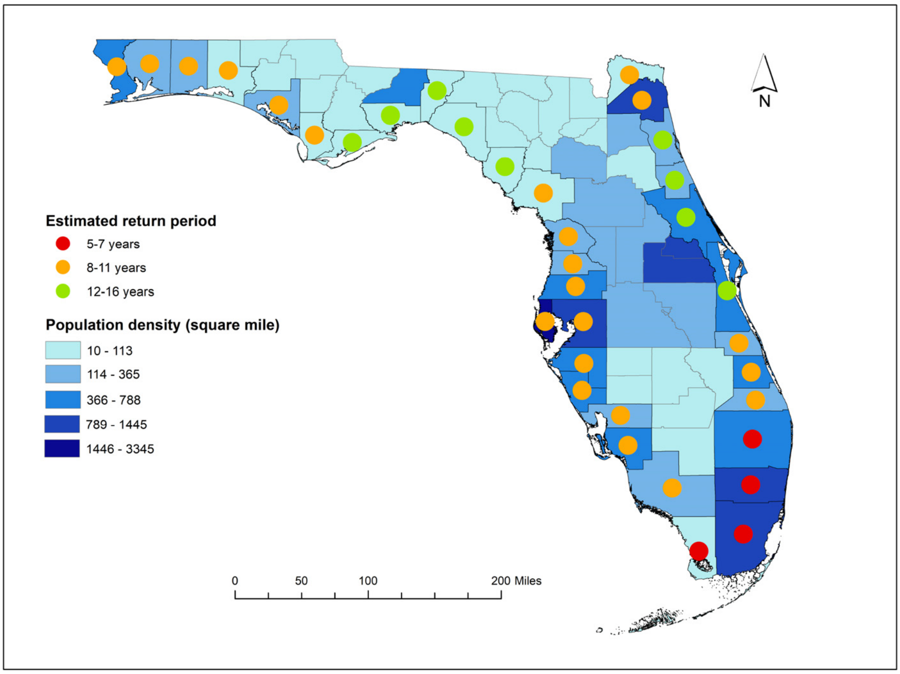

Figure 4.2. Historical distribution of hurricane landfalls in Florida.

Indirect Impact Pathways–Infectious Diseases

Climate change and variability and associated variable weather conditions can affect human health through indirect pathways (Fig. 4.1). These indirect impacts are modulated through biological and ecological processes that can influence infectious diseases (in particular, some water/food- and vector-borne diseases) and air quality. In this section, we focus on water/food-, and vector-borne diseases.

Disease Transmission Groupings

The impact of climate change and variability and associated weather events on infectious diseases has been receiving much attention in the past several decades. Across the globe, high human mortality rates and disability have been attributed to infectious diseases; climate change is intensifying and will continue to exacerbate transmission of infectious diseases, poses increasing concerns (Patz et al. 2005). Indeed, the transmission of many infectious diseases is closely linked to physical environmental factors, such as water and temperature. Many water-associated and zoonotic pathogens, for instance, which account for more than 75% of known pathogens causing human diseases, are associated with hydrological process (WHO 2003). From a transmission perspective, infectious diseases can be broadly classified into two groups: 1) directly transmitted (i.e., those spread directly from person to person via direct contact or droplet exposure, such as influenza and tuberculosis); and 2) indirectly transmitted, including those mediated through an intermediate vector organisms (vector-borne) or through environmental media such as water and soil (environmentally-mediated) (Eisenberg et al. 2007). Because the diseases in the indirectly transmitted group are either directly or indirectly related to water, this group can be further broken down into the following sub-groups based on water's role in disease transmission: waterborne (e.g., cholera typically via fecal-oral transmission), water-based (e.g. part of the pathogen life cycle requires aquatic environment, such as schistosomiasis), and water-related (e.g., malaria and dengue, which need water for breeding of insect vectors to fulfill the transmission cycle) (Yang et al. 2012; Mordecai et al. 2013; Ryan et al. 2015; Johnson et al. 2015; Mordecai et al., 2017) .

Climate-Sensitivity of Microbial Agents and Their Associated Diseases

Table 4.1 lists some of the major pathogens and their associated diseases that are climate sensitive and associated with water. These disease-causing pathogens, either through infection or toxin-generating (e.g. caused by protozoa, bacteria, virus, helminth, or algae), and their associated vectors (e.g., snails, mosquitoes, sand flies) are very small in size and lack thermostatic mechanisms (i.e. lack of function to maintain body temperatures). Their biological (e.g., survival, reproduction, development/growth, and infectivity) and environmental (e.g., contamination and movement) processes are determined by environmental conditions, such as rainfall, storm runoff, temperature, and sunlight. Climate change and variability and associated weather events are expected to affect both fresh and marine water environments thereby changing humans' exposure to these water-related contaminants or pathogens that cause ill health.

a) Waterborne Diseases

Waterborne diseases remain an important contributor to the global burden of disease (Pruss et al. 2002; Yang et al. 2012; Pruss-Ustun et al. 2014). Many different viral, bacterial, and parasitic diseases have been associated with waterborne transmission (Table 4.1). Human exposure to waterborne pathogens is primarily through drinking water, recreational water (e.g. via accidental drinking and, for some pathogens, via dermal contact), or foods. The distribution of these pathogens exhibits significant geographical variations, depending on both physical environmental and socio-economic conditions (Yang et al. 2012). For example, waterborne cholera, viral hepatitis, and some other water-based and water-related diseases (e.g., schistosomiasis and onchocerciasis) are largely confined to certain tropical areas where the prevalence of such diseases is largely due to lack of access to improved drinking water, sanitation and hygiene (Pruss et al. 2002), while some pathogens, such as *Cryptosporidium parvum*, *Giardia duodenalis*, and *Campylobacter* spp. have a much wider geographical distribution (Yang et al. 2012). Regardless of the geographical region, heavy rainfall, flooding, and temperature are among the most important factors associated with transmission and outbreaks of these waterborne diseases.

There is mounting evidence that weather events are often an important factor triggering waterborne outbreaks. In developed countries, extreme weather events such as excessive rainfall and flooding can overwhelm water treatment plants and/or increase runoff into recreational water, leading to water contamination that causes outbreaks (Kistemann et al. 2002). Some recent studies have clearly indicated that excessive rainfall has been a significant contributor to waterborne outbreaks. An analysis of historical records of 548 waterborne outbreaks in the US reported between 1948 and 1994 suggested a significant association between the outbreaks and rainfall—51% of waterborne disease outbreaks were preceded by precipitation events above the 90^{th} percentile and 68% by events above the 80^{th} percentile; the strongest association was between the outbreaks and surface water contamination due to extreme precipitation (Curriero et al. 2001). In Canada, Thomas et al. examined extreme rainfall and spring snowmelt in relation to 92 Canadian waterborne disease outbreaks that occurred between 1975 and 2001. They found that warmer temperatures and extreme rainfall were significant contributing factors to waterborne disease outbreaks in Canada (Thomas et al. 2006). Similar studies have been conducted in England (Nichols et al. 2009), the Netherlands (Schijven and de Roda Husman 2005), Finland (Miettinen et al. 2001), Denmark (Laursen et al. 1994), and Taiwan (Chen et al. 2012). In many developing countries, lack of access to improved drinking water and sanitation exacerbates the impact of these extreme precipitation weather events on waterborne diseases. Diarrhea, caused by many waterborne pathogens, remains a top killer of children under five in the developing world, particularly in Africa (Pruss-Ustun et al. 2014). A large number of studies have been carried out in the developing world. For example, cholera outbreaks caused by toxigenic Vibrio cholerae have been consistently shown to be correlated with excessive rainfall, flooding, and high temperatures in the epidemic areas of West Africa and Bangladesh (Mhalu et al. 1987; Hashizume et al. 2008; Luque Fernandez et al. 2009; Ngwa et al. 2016), although the exact mechanistic relationships that result in this correlation remain elusive (Colwell et al. 1998). Significant (positive) relationships have been reported between excessive rainfall and/or high temperatures and diarrhea in the Pacific Islands (Singh et al. 2001), Ecuador (Carlton et al. 2014), and Sub-Saharan Africa (Bandyopadhyay et al. 2012), while evidence also suggests that low rainfall and even drought can also be associated with diarrhea, as reported in Bangladesh (Hashizume et al. 2008) and Denmark (Senhorst and Zwolsman 2005).

b) Waterborne Diseases and Climate Impact in Florida

Across the US, climate change and variability and associated weather events are affecting and are expected to continue to affect both marine and freshwater resources. These effects extend to some water-associated pathogens and related diseases. In Florida, waterborne and foodborne diseases of major public health concerns are highlighted in Table 1. Enteric bacteria, protozoan parasites, enteric viruses including *Salmonella enterica*, *Campylobacter* spp., toxigenic *Escherichia coli*, *Vibrio* bacteria species, *Cryptosporidium* and *Giardia* enteroviruses, rotaviruses, noroviruses, and hepatitis A and E, are among those closely related to drinking and recreational waters, and shellfish. These pathogens, while in environmental stages, are sensitive to temperature, precipitation, and water flow. Several important toxin producers of water sources are of particular public health importance in Florida (Table 4.1) including toxins from harmful algal blooms, toxigenic marine species of *Alexandrium* (causing paralytic shellfish poisoning), *Karenia brevis* (causing neurotoxic shellfish poisoning), and *Gambierdiscus* spp. (causing ciguatera fish poisoning). Human exposure pathways are primarily through the consumption of contaminated shellfish and fish, and in recreational waters. Cyanobacteria, consisting of multiple species, can produce toxins (including microcystin), and the primary human exposure is from drinking water and recreational water. For all of these harmful algal blooms species, temperature, and precipitation are among the important factors affecting their reproduction, growth, and distribution.

Fig. 4.3 shows yearly distribution of total reported outbreaks and cases of food-borne and waterborne diseases in Florida from 1989 to 2011 and Fig. 4.4 shows the monthly distribution of reported outbreaks and cases for 2011, exhibiting marked annual variations and distinct seasonal distribution. According to the BRACE report for the period 2004–2012, approximately 1,150 cases of campylobacteriosis were reported annually, with the majority of cases reported between May and September. From that same report, ~426 cases of cryptosporidiosis were reported annually, with the majority of cases reported between June and October. Approximately 940 cases of giardiasis were reported annually, with an annual incidence rate of 5.1 cases per 100,000 population and the majority of cases reported between May and October. Salmonellosis accounted for the greatest number of foodborne illnesses reported, with an average of 5,438 cases reported each year and ~70% reported between June and November. Finally, ~101 cases of vibriosis were reported annually, with 81% of the cases reported between April and October (FDH 2015b). Focusing on the five diseases—campylobacteriosis. cryptosporidiosis, giardiasis, salmonellosis, and vibriosis—the BRACE study identified a total of 1,231 follow-up days of interest including 775 control days and 456 impact days—42 associated with hurricanes and 414 with tropical storms (FDH 2015b); the result suggested that the occurrences of cryptosporidiosis and salmonellosis were significantly associated with the tropical cyclones, with the risk ratio being 1.26 (95% CI, 1.04, 1.52) and 1.35 (95% CI, 1.29, 1.42), respectively (FDH 2015b).

Table 4.1. A list of climate-sensitive, water-associated agents and related illnesses.

Transmission Grouping	Organism	Disease	Main Exposure Pathways	Main Illness & Symptoms
	Protozoa			
Waterborne	*Cryptosporidium parvum*	Cryptosporidiosis	Fecal-oral via water (D,R)	Diarrhea, stomach pain, weight loss, and fatal for immunocompromised people
	Giardia duodenalis	Giardiasis	Fecal-oral via water (D,R)	Diarrhea, stomach pain, weight loss
	Cyclospora cayetanensis	Cyclosporiasis	Fecal-oral via water (D)	Diarrhea, stomach pain, weight loss
	Entamoeba histolytica	Amebiasis	Fecal-oral via water (D)	Diarrhea, stomach pain, dysentery
	Toxoplasma gondii	Toxoplasmosis	Water (D, F), congenital	Fever, damage on brain, eye, fetal damage in pregnant woman
Water-related (Vector-borne)	*Plasmodium* SPP	Malaria	Bite by mosquitos	Fever, chills, headache, sweats, fatigue, nausea
	Trypanosoma SPP	African trypanosomiasis	Bite by tsetse fly	Chancre, sleeping sickness, fever, headache, fatigue, can be fatal
	T. cruzi	Chagas disease	Bite by triatomine bug, contaminated (F), and others	Fever, fatigue, headache, rash, diarrhea, vomiting
	Leishmania SPP	Leishmaniasis	Bite by sand fly	Fever, weight loss, spleen/liver enlargement (visceral), skin sores (cutaneous)
	Viruses			
Waterborne	Hepatitis A, E virus	Viral hepatitis	Contaminated water (D, R, F)	Hepatitis
	Norovirus	Viral gastroenteritis	Contaminated water (D, R,F)	Vomiting and diarrhea
	Enteroviruses	Various	Contaminated water (D,R,F), contact	Various
Water-related (Vector-borne)	DENV 1, 2, 3, 4	Dengue hemorrhagic fever (DHF)	Bite by mosquito	Fever, severe headache, severe joint, muscle and bone pain, rash, bleeding
	Japanese encephalitis virus	Japanese encephalitis	Bite by mosquito	Fever, headache, vomiting, movement disorder, seizures
	West Nile virus	West Nile virus disease	Bite by mosquito	Most cases asymptomatic, febrile illness, encephalitis or meningitis
	St. Louis encephalitis virus	St. Louis encephalitis	Bite by mosquito	Most cases asymptomatic, fever, headache, dizziness, nausea, and malaise
	Chikungunya virus	Chikungunya	Bite by mosquito	Fever, joint pain and swelling, muscle pain, rash
	Eastern equine encephalitis virus	Eastern equine encephalitis	Bite by mosquito	Rare in humans, headache, high fever, chills, and vomiting in severe cases
	La Crosse encephalitis virus	La Crosse encephalitis	Bite by mosquito	Most cases asymptomatic, fever, headache, nausea, vomiting, and tiredness

Transmission Grouping	Organism	Disease	Main Exposure Pathways	Main Illness & Symptoms
	Bacteria			
Waterborne	Vibrio cholerae	Cholera	Contaminated (D, F)	Severe diarrhea, vomiting, muscle cramps
	Vibrio SPP	Vibriosis	Contaminated Shellfish, open wound	Diarrhea, septicemia
	Salmonella spp.	Salmonellesis	Contaminated (F, less D)	Diarrhea, abdominal pain, fever
	Salmonella typhi	Typhoid	Contaminated (D, F)	Fever, malaise, abdominal pain, can be fatal
	Shigella spp.	Shigellosis	Contaminated (D, F)	Diarrhea, fever, and stomach cramps
	Campylobacter spp.	Campylobacteriosis	Contaminated (D, F, R)	Diarrhea, fever, and stomach cramps
	Enterotoxigenic *E. coli*	Diarrheal illness	Contaminated (D,F)	Diarrhea, abdominal cramping, fever, nausea, muscle aches
	Enterohaemorrhagic E. coli	Diarrheal illness	Contaminated (D,F)	Bloody diarrhea, and haemolytic-uraemic syndrome
	Yersinia spp.	Yersiniosis	Contaminated (D,F)	Diarrhea, fever, abdominal pain
Water-related (Vector-borne)	*Francisella tularensis*	Tularaemia	Bites of tick or deer fly, contact with infected animals, can be through air, water	Mild skin lesion to life-threatening pneumonic
	Helminths			
Water-based	*Schistosoma* spp.	Schistosomiasis	Dermal contact with water	Diarrhea, urinary and intestinal damage
	Dracunculus medinensis	Dracunculiasis	Contaminated (D)	Painful ulcer and inflammation
	Ancylostoma duodenale and Necator americanus	Hookworm infection	Dermal contact with soil	Diarrhea, loss of appetite, fatigue, and anemia
	Ascaris lumbricoides	Ascaris	Fecal-oral (D, F)	Abdominal discomfort, growth retardation in children
	Trichuris trichiura	Whipworm infection	Fecal-oral (D,F)	Bloody and watery stool, growth retardation
Water-related	*Wuchereria bancrofti*	Lymphatic filariasis	Bite by mosquito	Most asymptomatic, lymphedema, pulmonary eosinophilia
(Vector-borne)	*Onchocerca volvulus*	Onchocerciasis	Bite by blackfly	Skin rash, eye disease, and nodules under the skin
	Loa loa	Loiasis	Bite by deerfly	Itchy, muscle and joint pain, fatigues, eye worm
	Algae			
Water-related	Cyanobacteria	Various	Exposure to toxins via D and direct contact	Dermatitis, intestinal illness, liver damage, neurotic reactions
	Alexandrium spp	Paralytic shellfish poisoning	Contaminated (F) by toxin	Circumoral and extremity paresthesia, respiratory paralysis
	Karenia brevis	Neurotoxic shellfish poisoning	Contaminated (F) by toxin	Gastrointestinal symptoms, paresthesia, respiratory and eye irritation
	Gambierdiscus spp	Ciguatera fish poisoning	Contaminated (F) by toxin	Diarrhea, vomiting, malaise, extremity paresthesia

Note: 1. Abbreviations for main exposure pathways: drinking water (D), recreational water (R), and foods (F); 2. Highlighted in red indicates pathogens/diseases of major public health significance in Florida.

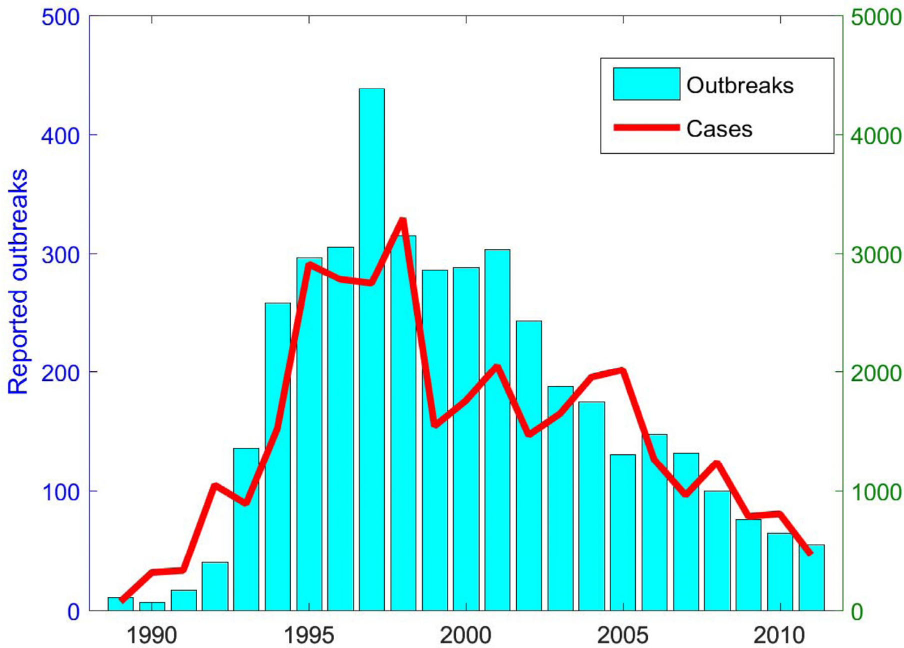

Figure 4.3. Reported outbreaks (bar) and human cases (line) of food-borne and waterborne diseases in Florida each year from 1989 to 2011 (Source: Florida Department of Health). Toxigenic V. cholerae infections are highly unusual in Florida and the first V. cholerae O75 outbreak was detected and reported in Florida between March 23 and April 13, 2011.

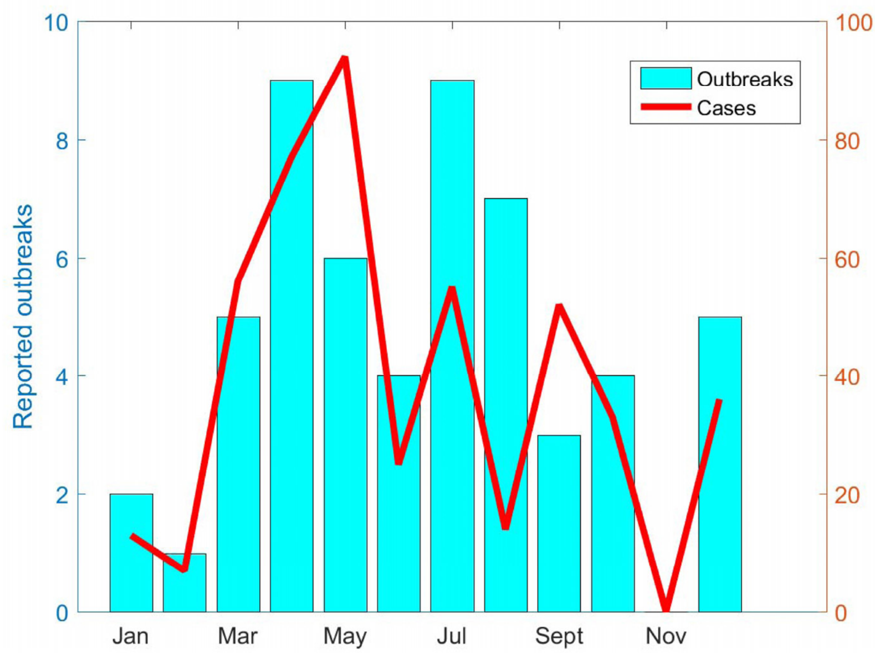

Figure 4.4. Monthly distribution of reported outbreaks and cases of food-borne and waterborne diseases in Florida, 2011 (Source: Florida Department of Health)

c) Vector-Borne Diseases

Vector-borne diseases pose serious public health threats throughout the world. According to the World Health Organization, vector-borne diseases account for more than 17% of infectious diseases, causing more than one million deaths annually from diseases such as malaria, dengue fever, yellow fever, Japanese encephalitis, and schistosomiasis (WHO 2016). Vector-borne diseases are transmitted through vector organisms including mosquitoes, ticks, flies, fleas, and snails. The transmission of vector-borne diseases takes two primary transmission pathways. The first is the human-vector pathway, with transmission through a vector biting a host; pathogens survive outside hosts in arthropod vectors and humans are typically the only host (Eisenberg et al. 2007). Diseases in this group include malaria, dengue fever, onchocerciasis, trypanosomiasis, and filariasis (Table 4.1). The second pathway involves zoonotic transmission, with a vector biting a nonhuman host as the transmission route and humans as the dead-end host (Eisenberg et al. 2007). Diseases in this group include Lyme disease, Yellow fever, West Nile virus, and Japanese encephalitis (Table 4.1). The transmission and spread of vector-borne diseases are determined by complex interactions between the host (either human or nonhuman), the vector (e.g., mosquitos, flies, snails, and ticks), and various pathogens ranging from protozoans, viruses, bacteria, and helminthes (Table 4.1). Important biological properties underlying the transmission of vector-borne diseases include survival, development, and reproduction of the vector; also the pathogens in the vector, the vector's biting rate, and the behavior of hosts (human and nonhuman), all of which are associated with climatic conditions. The following sections discuss some specific aspects of the effects of rainfall, temperature, and flooding with regard to vector-borne diseases.

Temperature Sensitivity

Through the modulating effects on physiological activities and tolerance limits of vectors and infectivity of pathogens, temperature can affect distribution of the vector and transmission of the pathogens between vectors and hosts. Some key mechanistic effects of temperature on vectors, vector-borne pathogens and their transmission are summarized by Gulber et al. (2001).

- Change in survival of vectors (e.g. increase or decrease depending on species)
- Change in susceptibility of vectors to pathogens
- Change in vector population growth
- Change in feeding behavior and host contact
- Change in incubation period of pathogens in vectors (e.g. decreased extrinsic incubation period at higher temperatures)
- Change in pathogen replication and infectivity
- Change in transmission season

A large number of studies on vector-borne diseases at different scales have provided empirical evidence and predictions on the climatic factors and vector-borne disease links. For example, studies have shown significant relationships between ambient temperature and malaria transmission for both mean temperature (Loevinsohn 1994; Lindblade et al. 2000; Thomson et al. 2005; Tian et al. 2008; Wardrop et al. 2013) and its daily fluctuations (Paaijmans et al. 2010). Laboratory studies have shown clear temperature-dependent effects on dengue virus infection in mosquitoes (Alto and Bettinardi 2013). Fluctuations at a low mean temperature accelerate dengue virus transmission in *Aedes aegypti* mosquitoes (Carrington et al. 2013). A recent systematic review and meta-analysis based on 137 studies on the relationship between dengue risk and temperature suggests that the dengue transmission and risk are sensitive to temperature, with a positive relationship between them for a minimum range (18.1–24.2 °C) to a maximum temperature range (28.0–34.5 °C) (Fan et al. 2014). A regional predictive study reported that increased temperature increases the likelihood of many vector-borne diseases, in particular malaria, dengue fever, and Lyme disease in new areas (Githeko et al. 2000). Similar findings are also reported for West Nile virus (Soverow et al. 2009). These empirical findings have been used to parameterize mechanistic models of temperature driven transmission for vector-borne diseases, which can be coupled to projected climate scenarios to anticipate shifting geographies of transmission risk, e.g. for malaria (Mordecai et al. 2013; Johnson et al. 2014; Johnson et al. 2015; Ryan et al. 2015; Ryan et al. 2015) and for *Aedes* spp transmitted diseases of concern for Florida: dengue, chikugunya, and zika viruses (Moedecai et al. 2017; Ryan et al. 2017).

Rainfall

Rainfall can supply water to both transient and persistent environments that can serve as habitats or breeding sites for vectors and/or for part of pathogens' lifecycles, critical for transmission of vector-borne diseases. Meanwhile, rainfall can also have negative impacts on the habitats (for example, washing away), thereby reducing the transmission risk. Variations in rainfall may have direct and indirect impacts on the distribution and timing of transmission of vector-borne diseases. Some key mechanistic effects of rainfall on vectors, vector-borne pathogens, and their transmission are summarized by Gubler et al. (2001).

- Increased rain may increase larval habitat and vector population.
- Excess rain (e.g. causing flooding) may eliminate habitat for both vector and hosts.
- Increased humidity may increase vector survival and biting rate.
- Increased rainfall may facilitate transport of pathogens for certain distance (Liang et al. 2007).
- Increased rain may increase vertebrate host size through increased food availability (e.g. vegetation).
- Flooding may decrease vertebrate host size (e.g. reduced food availability) but increase interactions (e.g. contacts) with humans.

Such mechanistic links have been reported by many studies including for diseases such as malaria (van der Hoek et al. 1997; Thomson et al. 2005; Galardo et al. 2009; Gao et al. 2012; Yang et al. 2012), dengue fever (Li et al. 1985; Su 2008; Johansson et al. 2009; Banu et al. 2011;

Hii et al. 2012), West Nile virus (Shaman et al. 2005; Soverow et al. 2009), and Lyme disease (Ogden et al. 2006; Ostfeld et al. 2006).

Vector-Borne Diseases in Florida

In the United States, 14 vector-borne diseases are of primary public health concern. Table 4.2 lists key notifiable vector-borne diseases and reported cases between 2013 and 2015 in Florida. Major mosquito-borne diseases include the St. Louis encephalitis virus, West Nile virus, Eastern equine encephalitis virus, Western equine encephalitis virus, Venezuelan equine encephalitis virus, Everglades virus, and the California serogroup viruses including La Crosse encephalitis virus, all of which are transmitted by mosquitoes. More recently, concern about *Aedes spp* transmitted flavivirus and alphaviral disesaes have become more prevalent: dengue (DENV), chikungunya (CHIKV), and zika (ZIKV). The 2015-2016 global public health emergency for Zika declared by the WHO focused attention on Florida as an introduction and establishment gateway for the U.S.

Table 4.2. A summary of reported case counts of notifiable vector-borne diseases in Florida. (Source: Florida Department of Health).

Diseases	2013-2015 Reported Cases	Number of Counties Reported
Tick-borne		
Lyme disease	459	46
Spotted Fever Rickettsia	74	18
Anaplasmosis/Ehrlichiosis	82	30
Tularemia	2	2
Mosquito-Borne		
West Nile virus	37	14
Malaria	146	24
Dengue	331	31
California serogroup viruses	2	2
Eastern equine encephalitis	3	3
St. Louis encephalitis	2	1

St. Louis Encephalitis. The St. Louis encephalitis virus, a flavivirus, was the most common mosquito-transmitted human pathogen in the U.S. prior to the introduction of the West Nile virus in 1999 (FDH 2016). In Florida, the principal vector is *Culex nigripalpus*, a ubiquitous species throughout the state. No human case has been reported in Florida since 2003. However, sentinel chickens testing positive for antibodies to the St. Louis encephalitis virus have been reported in several counties in Central and South Florida, suggesting the potential for a possible resurgence (FDH 2014, 2016).

West Nile virus. The peak period of transmission in Florida for the West Nile virus is July through September. The natural cycle of West Nile virus involves *Culex* mosquitoes and wild birds. Between 2001 and 2013, 318 human West Nile virus cases were reported in Florida and

West Nile virus activities have been consistently reported in many counties around the state (FDH 2014).

Eastern Equine Encephalitis. Eastern equine encephalitis occurs in natural cycles involving birds and *Culiseta melanura* in freshwater swampy areas, with a peak in transmission occurring between May and August. Historical and current evidence indicates limited human Eastern equine encephalitis epidemic potential in Florida (FDH 2014, 2016).

Dengue Fever. In Florida, a historical dengue fever epidemic occurred in 1934-1935 and then it ceased. It re-emerged in 2009, and since then a small number of cases have been reported each year among individuals who had previous travel to dengue-endemic countries. In the summer of 2009, local dengue transmission was identified in Key West, Florida. Since then, sporadic local transmission has been identified in other Central and South Florida counties during 2010, 2011, 2012, and 2013 (FDH 2014, 2016). The presence of the *Aedes spp* mosquito, both *Aedes aegypti*, also known as the Yellow Fever mosquito, which has been a persistent invasive mosquito in Florida for a couple of centuries, and the more recently introduced Asian Tiger Mosquito, *Aedes albopictus*, maintain transmission potential in Florida. *Aedes* mosquitoes are capable of breeding in as little as a teaspoon of water, and are able to adapt well to urban environments, and exhibit transmission of dengue, chikungunya, and zika, at temperature ranges found almost year-round in most of Florida (Mordecai et al. 2017). The optimal transmission temperature range for *Aedes aegypti*, in particular, is higher than that for *Aedes albopictus*, suggesting that future climates will promote *Ae aegypti* transmission in Florida, before it becomes too hot for transmission (Ryan et al. 2017).

Malaria. Malaria is caused by the mosquito-borne parasite *Plasmodium falciparum*. Endemic malaria was eliminated in Florida in the late 1940s. However, imported cases—either from travelers returning to the state from malaria-endemic regions or tourists carrying the pathogen—have been reported. The *Anopheles* mosquitoes responsible for transmitting the malaria parasite to humans are common in the state so establishment of local transmission is still possible (FDH 2014, 2016).

Tick-Borne Diseases. The most common tick-borne diseases are ehrlichiosis, anaplasmosis, Lyme disease, Rocky Mountain spotted fever, and other spotted fever illnesses. Lyme disease is the most commonly reported vector-borne disease in the United States. It is caused by a bacteria known as *Borrelia burgdorferi*. Lyme disease is reported in Florida year-round. An estimate suggests that about 23% of cases were acquired in Florida and about 77% were acquired while travelling to other states or countries (FDH 2016). *Ehrlichiosis and Anaplasmosis*—several pathogenic species in the genus *Ehrlichia* and *Anaplasma*—can cause human illness. The human illness caused by *Ehrlichia chaffeensis* is called Human Monocytic Ehrlichiosis, and the illness caused by *Anaplasma phagocytophilum* is called Anaplasmosis or Human Granulocytotropic Anaplasmosis. In Florida, the majority of Human Monocytic Ehrlichiosis cases (73%) are acquired in Florida, primarily in the northern and central parts of the state, and Human Granulocytotropic Anaplasmosis cases are even more likely to be acquired in Florida. Cases are reported year-round, with a peak occurring during the spring and summer months (FDH 2016). *Rocky Mountain Spotted Fever* is a disease is caused by the bacterium *Rickettsia richerrsii* and, in Florida, it is transmitted primarily by the American dog tick. It can also be caused by *Dermacentor variabilis* and cases of this transmission are reported year-round with more than 70% acquired in Florida, and the majority of cases are reported in the northern and central regions of the state (FDH 2016).

Drought

Drought is considered a meteorological anomaly characterized by a prolonged and abnormal moisture deficiency. Climate change and variability are progressively increasing the severity and frequency of drought events. Drought has many possible public health implications (Kalis et al. 2009; Kalis and Curtiss 2016). Drought may:

- Compromise quantity and quality of water for drinking, sanitation, and hygiene
- Compromise air quality (e.g. increased particulate matters in the air)
- Reduce crop yield, food availability and nutrition
- Increase or decrease risks to infectious pathogens (e.g. waterborne, air-borne, and vector-borne)
- Increase risk of non-communicable illness (e.g. respiratory infections and/or illness)

Drought has been linked to deterioration of water quality (Golladay and Battle 2002; Al-Kharabsheh and Ta'any 2003) and air quality (Taylor and Davies 1990; Field et al. 2009) in various settings in both the developed and developing world. Drought has been implicated for infectious diseases—waterborne (Lipp et al. 2002; Schuster et al. 2005; Senhorst and Zwolsman 2005), vector-borne (Chretien et al. 2007; Erlanger et al. 2009; Medlock and Leach 2015), and airborne (Polymenakou et al. 2008). Drought conditions have also been linked to increased incidence of respiratory diseases (Smith et al. 2014).

In Florida, the BRACE study examined associations between monthly drought conditions (using the Standardized Precipitation Index), disease rates and emergency department visits for specific health conditions (e.g. allergic rhinitis, asthma, and all respiratory diseases excluding asthma) among Florida residents from 2005 to 2012. The results suggested that drought was significantly associated with emergency department visits for respiratory diseases. It is worth noting that the relationship between the most extreme drought conditions and emergency department visits tended to be protective (e.g. less emergency department visits for respiratory illness), while more moderate drought appeared to be associated with an increase in emergency department visits for the health conditions. A similar pattern was also observed for asthma (FDH 2014b).

Indirect Impact Pathway – Mental Health, Well-Being, and Community Health

Mental health disorders and well-being are an important aspect of the human health impacts associated with climate change and variability, and associated weather events. Many mental health consequences, ranging from simple stress and distress symptoms to some severe conditions including anxiety, distress, posttraumatic stress disorder (PTSD), and even suicidal tendency have been the focus of much of the research and public health responses in the past few decades. Here are some key mental disorders and community health issues that may be related to climate change and associated weather events, based on the U.S. Global Change Research Program report (Crimmins et al. 2016).

Experience with extreme weather events, such as flooding, drought, and hurricanes, may cause the following mental disorders:

- Increased stress, anxiety, depression, grief, and even suicidality;
- Increased tensions on social stress and relationships;
- Increased substance abuse; and
- Increased risk of PTSD.

At the community level (Crimmins et al. 2016), potential impacts may include:

- Increased interpersonal aggression,
- Increased violence and crime,
- Increased social instability, and
- Decreased community cohesion.

Assessing the impacts of natural disasters on mental or community health and well-being of affected populations, as well as mediation techniques, has been a focus of much research, community and public health responses. In Florida, studies have suggested that anxiety disorder, major depressive episodes, and PTSD among affected populations could be significantly associated with storm exposure and displacement during the occurrence of Hurricane Andrew in 1992 (David et al. 1996), as well as a number of hurricanes in 2004 (Acierno et al. 2007) and 2012 (Neria and Shultz 2012). Studies have also indicated that social support would help to alleviate such negative impacts (Acierno et al. 2007). Similar impacts have been reported for community and public health workers who responded to these weather events. For example, during the 2004 Florida hurricane season, four hurricanes (Charley, Frances, Ivan, and Jean) as well as one tropical storm (Bonnie) hit Florida during a period of seven weeks. Increased PTSD, other mental health issues, and substance abuse were reported among public health workers during and after these events (Fullerton et al. 2013; Fullerton et al. 2015). The studies also suggested that these mental health outcomes were influenced by multiple community characteristics including the collective efficacy of neighborhood populations in the community.

Significantly lower depressive symptoms were associated with communities that had sufficient resources and received social support (Acierno et al. 2007, Fullerton et al. 2013, Fullerton et al. 2015).

Impacts on children following natural disasters are of particular concern. For example, Hurricane Andrew was a devastating category 5 Atlantic hurricane that struck South Florida in 1992. Studies showed significant impacts of hurricane exposure, stressors occurring during the hurricane, and recovery periods on children's persistent posttraumatic stress. In the Miami-Dade County area, 35% to 60% of children surveyed reported moderate to very severe levels of posttraumatic stress symptoms (Vernberg et al. 1996; La Greca et al. 2010), with hurricane-related stressors influencing children's persistent posttraumatic stress symptoms and other life events in later stages of children's life (La Greca et al. 2010; Weems et al. 2010; La Greca et al. 2013). These findings have important community health implications for identifying and potentially helping youth in the aftermath of natural disasters.

Conclusion

The current available evidence has clearly indicated increases in average temperature, total annual precipitation, frequency of extreme temperature conditions and heavy precipitation in the United States in the past five decades, as well as increases in the tropical cyclone activity in regions along the Atlantic Ocean, the Caribbean, and the Gulf of Mexico. Similar patterns are expected in the future if no remediation is conducted (USEPA 2016). Florida is likely to face even greater effects than the rest of the US, particularly effects associated with sea level rise, heat waves, storm surge, hurricanes, and others (FOCC 2010) that affect human health in a variety of different ways. Some effects are through direct exposure pathways, such as hurricane/storm and temperature-related illnesses, injuries, and deaths. Some are through indirect exposure pathways such as waterborne and vector-borne diseases. And still others are through social and economic pathways, such as stress and mental illness. In addition to these direct and indirect effects, we see coupled and compounded effects of climate change, which are anticipated to be exacerbated in the future. For example, Florida is home to a large elderly population; the warm climate and housing development capacity made this ideal. However, the elderly are more vulnerable to the effects of heatwaves, less mobile in the event of hurricanes, and suffer greater impacts of the symptomology of febrile vectorborne diseases. This puts the state in a position higher public health urgency by virtue of an interaction of demographic profile and increased impact of climate change due to geography. Given the increase in hurricances and storm impacts expected under climate change, we are likely to also see the added impact of vectorborne disease risk anticipated in the aftermath of such disasters. For example, the additional potential vector breeding sites provided by debris and damaged infrastructure after hurricanes have been noted as concerns for Zika transmission in the 2016-2017 hurricane season. An additional component of this is the unanticipated exposures post-disaster, in which both displaced residents and rescue workers have radically increased outdoor exposure, reduced access to air conditioned spaces, and to basic protection measures such as insect repellent and appropriate protective clothing. These are just two of the compounded scenarios of public health concern that the state of Florida faces in a changing climate. Despite the comprehensive information reviewed in the chapter, many things are still unknown or are not well understood about the health impacts of Florida's changing climate. For instance, what are the impacts of sea level rise, flooding, and other extreme weather events on water contamination that will ultimately influence human health? How will future warming trends and other climate-sensitive hazards influence the transmission and spread of existing and/or new waterborne and vector-borne diseases? What are the disease burdens and their distributions attributable to known climate-sensitive hazards in the state? To address these challenges, policies focused on mitigation, adaptation strategies, health surveillance, and research that could close knowledge gaps on human exposures to these climate-sensitive hazards and associated health impacts are much needed.

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