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ENVIRONMENTAL HEAT IN RELATION TO CHILD HEALTH OUTCOMES

by

KATHLEEN FITZSIMMONS

B.A., Colgate University, 2001
M.P.H., Boston University, 2006

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ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

Approved by

First Reader ____
Martha Werler, DSc, MPH
Professor and Chair of Epidemiology

Second Reader ____
Matthew Fox, DSc, MPH
Professor of Epidemiology
Professor of Global Health

Third Reader ____
Barbara E. Mahon, MD, MPH
Adjunct Assistant Professor of Epidemiology

Director, Division of Bacterial Diseases
National Center for Immunization and Respiratory Diseases
U.S. Centers for Disease Control and Prevention

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ENVIRONMENTAL HEAT IN RELATION TO CHILD HEALTH OUTCOMES

KATHLEEN FITZSIMMONS

Boston University School of Public Health, 2020

Major Professor: Martha Werler, DSc, MPH, Professor and Chair of Epidemiology

ABSTRACT

In the United States, annual average temperature is projected to rise throughout the 21st century, and both extremely hot days and heat waves are expected to become more intense and frequent. Global climate change is already negatively affecting human health and with continued warming, adverse health outcomes are expected to be exacerbated, especially among already susceptible populations, like children.

This dissertation responds to the call for scientific research on potential health consequences of climate change among children. Pregnant women and children, especially infants, are considered vulnerable to a number of climate-sensitive health outcomes, including heat stress, respiratory disease, and diarrheal illness. Specifically, with the three studies described here, we aimed to contribute to the growing body of research establishing baseline relationships between environmental heat and child health outcomes in the United States. For Studies 1 and 2, we examined exposure to heat wave, defined multiple ways, in relation to preterm birth and pediatric asthma, respectively, using meteorological data from University of Massachusetts, Lowell and health data from the Massachusetts Department of Public Health. The first study overall found little to no short-term association between maternal heat wave exposure and preterm birth among women in ten large Massachusetts cities, using five definitions of heat wave. However, there were potential differences by gestational age that should be explored further in future studies. Findings from the second study provided some evidence for increased rates of emergency department (ED) visits for asthma/wheeze, among Massachusetts children during and immediately following heat waves, although excess numbers were small. Rates of all-cause pediatric ED visits were also elevated during heat waves and the days following, corresponding to hundreds of excess visits. For Study 3, we used national data from the U.S. Centers for Disease Control and Prevention's Laboratory-based Enteric Disease Surveillance system to evaluate the association between temperature-based season and incident *Salmonella* infection in infants. Results confirmed elevated rates of infant infection in the summer compared to winter and revealed a greater absolute impact among infants compared to other age groups, especially in the South and for *Salmonella* serotypes commonly from environmental, non-food sources.

Findings from this dissertation should not be viewed in isolation, but rather as part of a growing body of scientific literature on the potential impacts of climate change on child health. This work provides evidence that environmental heat is associated with certain adverse health outcomes among children in the U.S. and raises questions for further research. Results could be used as a baseline and compared with future estimates to assess changes in vulnerability and inform public health interventions.

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INTRODUCTION

The earth’s climate has experienced unprecedented warming over the last century largely due to increases in atmospheric levels of heat-trapping greenhouse gases from human activities (IPCC 2013; Hayhoe et al. 2018). Warming has occurred on all continents and global average temperature increased by about 1.8°F (1.0°C) from 1901 to 2016 (WHO 2002; Hayhoe et al. 2018). Collectively, 2014–2018 were the five warmest years since record keeping began in 1880 (NOAA 2018; NASA 2019). Across the contiguous United States, annual average temperature increased by 1.2°F (0.7°C) for the period 1986–2016 relative to 1901–1960 (Hayhoe et al. 2018). Additionally, days with record high temperatures have become more common in the U.S. over the past few decades, as have extreme heat events, or heat waves (Vose et al. 2017). Evidence suggests that heat wave frequency, duration, intensity, as well as the length of the heat wave season, have increased in recent decades (Habeeb et al. 2015;Vose et al. 2017).

According to the United Nations Intergovernmental Panel on Climate Change, by the late 21st century, most land areas will very likely experience more hot days with higher maximum temperatures, as well as more frequent and longer heat waves (IPCC 2013). In the U.S., annual average temperature is projected to rise throughout the 21st century, and both extremely hot days and heat waves are expected to become more intense and frequent (Vose et al. 2017; Hayhoe et al. 2018; Dahl et al. 2019). For instance, compared to a 1971–2000 baseline, the number of days each year that exceed a heat index of 100°F and 105°F are set to double and triple, respectively, by mid-century (Dahl et al. 2019). The northeast region of the U.S. is projected to experience the largest increase in temperature of any region in the contiguous U.S. over the coming decades, with average annual temperature rising 3.6°F (2°C) by 2035 compared to preindustrial temperatures (Dupigny-Giroux et al. 2018). The extent of projected warming beyond the next few decades corresponds closely with the level of global greenhouse gas emissions, although temperatures will rise with all emission scenarios. According to the most recent National Climate Assessment (Hayhoe et al. 2018), even with substantial emission reductions starting mid-century (lower scenario, RCP4.5), there would still be warming of 2.3°–6.7°F (1.3°–3.7°C) across the U.S. by 2080–2099 relative to 1986–2015. Continued increases in carbon emissions throughout the century (high scenario, RCP8.5) would result in warming of 5.4°–11.0°F (3.0°–6.1°C). Moreover, extreme heat conditions in the U.S. would be twice as frequent by late century under the high compared to lower emissions scenario (Dahl et al. 2019).

Climate change is already negatively affecting human health and with continued warming, adverse health outcomes are expected to be exacerbated, especially among already susceptible populations, like children (WHO 2002; Smith et al. 2014; Ebi et al. 2018). Pregnant women and children, especially infants, are considered vulnerable to a number of climate-sensitive health outcomes, including heat stress, respiratory disease, and diarrheal illness (WHO 2002; Balbus and Malina 2009; Sheffield and Landrigan 2011; Xu et al. 2012; Patz and Thomson 2018; Ebi et al. 2018). During pregnancy, the added physical and mental stress, along with factors like elevated core temperature from fat deposition, reduced capacity to lose heat through sweating, and increased heat production from weight gain, may make pregnant women more sensitive to increases in ambient temperature (Strand et al. 2011). Children are at increased risk based on age-related physiological, immunological, cognitive and behavioral factors that impact environmental exposure opportunities, levels, and effects. For instance, compared to adults, children breathe more air, drink more water, and consume more food per unit body weight (Sheffield and Landrigan 2011). In infants (< 1year of age), underdeveloped immune systems may make them more susceptible to enteric infection and severe diarrheal illness (Cohen 1991). Additionally, children have limited ability to alter their exposure to environmental hazards as they lack control over their surroundings, relying on adults to provide care (Sheffield and Landrigan 2011).

This dissertation responds to the call for scientific research on potential health consequences of climate change among children (McMichael et al. 2003; Portier et al. 2010; Sheffield and Landrigan 2011; MA Adaptation Report 2011; Pinkerton et al. 2012). According to the World Health Organization, establishing baseline relationships between weather and health is a key role for public health science (McMichael et al. 2003). Such research should be conducted at a regional level since populations with observed associations are thought to be particularly vulnerable to future changes in climate (Patz et al. 2014). Exposure, background rates of disease, and factors that mediate the impact of warming also vary by geographic area (WHO 2002; McMichael et al. 2003; Smith et al. 2014; Ebi et al. 2018).

Specifically, with the three studies described here, we aimed to contribute to the growing body of research establishing baseline relationships between environmental heat and child health in the United States. We chose to study health outcomes that are national public health priorities and for which there is some evidence that they are climate-sensitive (CDC 2014a). For Studies 1 and 2, we used Massachusetts-specific data to examine exposure to heat wave, defined multiple ways, in relation to preterm birth and pediatric asthma, respectively. For Study 3, used national data from the U.S. Centers for Disease Control and Prevention to explore the association between temperature-based season and incident salmonellosis in infants by geographic region and serotype, and assessed how the association differed from that among other age groups.

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ETHICS STATEMENT

The Boston University Institutional Review Board (IRB) approved the research proposal for this dissertation as non-human subjects research. Studies 1 and 2 were approved by the Massachusetts Department of Public Health IRB through the data request process. For Study 3, a data use agreement was completed with the U.S. Centers for Disease Control and Prevention to access the Laboratory-based Enteric Disease Surveillance data.

STUDY 1: EVALUATING THE SHORT-TERM EFFECT OF MATERNAL EXPOSURE TO HEAT WAVE ON PRETERM BIRTH IN MASSACHUSETTS

Introduction

Preterm birth, generally defined as delivery at less than 37 completed weeks of gestation, remains an important contributor to short-term and long-term morbidity and mortality (McIntire and Leveno 2008; Saigal and Doyle 2008). Globally, the burden is greatest in low-income countries, but high-income nations are also impacted (Blencowe et al. 2012; Liu et al. 2012). The incidence in the U.S. has historically been high compared to other developed countries; approximately one in ten births were premature in 2015 (Blencowe et al. 2012; Schoen et al. 2015; Martin et al. 2017).

Preterm birth is a leading cause of mortality among infants and young children, both worldwide and in the U.S., accounting for 35% of U.S. neonatal deaths in 2010 (Liu et al. 2012). Preterm infants are also at increased risk of motor and cognitive impairments and chronic disease (Saigal and Doyle 2008). A 2007 Institute of Medicine report estimated that preterm births in the US cost more than $26.2 billion each year, with nearly two-thirds of the cost attributable to medical care (Institute of Medicine 2007). This is considered a conservative estimate as it does not consider beyond early childhood many direct costs related to medical care, special education, therapy services, or caregiving, nor indirect costs related to lost productivity.

Addressing preterm birth is a global public health priority and is a Healthy People 2020 Leading Health Indicator in the U.S. (Blencowe et al. 2013; CDC 2014b; United Nations 2015). There is a recognized need for improved surveillance and more research into the etiology of preterm birth in order to take steps toward prevention (Barfield 2015).

Preterm birth is characterized by multiple etiology likely involving a complex mix of genetic, clinical, behavioral, socioeconomic and environmental factors (Institute of Medicine 2007; Goldenberg et al. 2008). Known risk factors include, multiple pregnancies (e.g., twins), short interpregnancy interval, prior preterm delivery, maternal medical conditions (e.g., diabetes, hypertension), intrauterine infection, stress, smoking, and extremes of prepregnancy body-mass index (Goldenberg et al. 2008; Blencowe et al. 2013). Maternal demographic characteristics associated with preterm birth include low and high maternal age, Black race (in the U.S.), low socioeconomic status, and single marital status (Institute of Medicine 2007; Murphy 2007; Goldenberg et al. 2008; Blencowe et al. 2013; Delnord et al. 2015).

The potential role of meteorological factors, including ambient temperature, in relation to preterm birth is not well understood (Murphy 2007; Goldenberg et al. 2008; Lee et al. 2008). It is biologically plausible that pregnant women may be particularly vulnerable to heat stress from increases in ambient temperature, which could trigger labor (Khamis et al. 1983; Lajinian et al. 1997; Wells and Cole 2002; Strand et al. 2011; Stan et al. 2013). In recent decades, epidemiologic research on the relationship between ambient temperature and preterm birth has been expanding. Although the findings have not been consistent, with some studies failing to find an association (Porter et al. 1999; Lee et al. 2008; Wolf et al. 2012; Auger et al. 2014; Vicedo-Cabrera et al. 2015), many provide evidence supporting a relationship between high environmental temperature and preterm birth, especially within a short time of exposure (Lajinian et al. 1997; Yackerson et al. 2008; Basu et al. 2010; Dadvand et al., 2011; Strand et al. 2012; Cox et al. 2016; He et al.

2016; Basu et al. 2017; Mathew et al. 2017; Ha et al. 2017; Son et al. 2019).

Three studies, one in Italy, one in Australia, and one in Alabama, U.S., specifically considered the impact of maternal heat wave exposure on preterm birth (Schifano et al. 2013; Wang et al. 2013; Kent et al. 2014). Overall, each study reported a positive association, yet the Australian and U.S. studies found that results varied across combinations of temperature thresholds and durations (Wang et al. 2013; Kent et al. 2014). In Italy, Schifano et al. (2013) did not look at how varying the definition of heat wave might impact their findings. Importantly, findings from these studies may not apply to the northeastern U.S., which climate models predict may be especially vulnerable to increases in summer temperatures and where such studies may be particularly relevant (Kalkstein and Greene 1997; McGeehin and Mirabelli 2001; Hayhoe et al. 2008).

The aim of this study was to examine the short-term effect of maternal exposure to heat wave on preterm birth among residents of ten Massachusetts cities. We used a case-crossover design in which each case served as her own control, evaluated effect modification by key factors, and assessed how the effect on preterm birth varied by heat wave definition, which could be important for specifying regional heat wave metrics for use in public health planning. The hypothesis evaluated was that short-term risk of preterm birth would be higher for women exposed to a heat wave compared to those who were not so exposed. We also hypothesized that we would observe a greater effect among women who were later in pregnancy and non-White, and less of an effect among older women.

Methods

Case Identification

Data on live births were obtained from the Massachusetts Department of Public Health (MDPH), Registry of Vital Records and Statistics. The study population consisted of live singleton births that occurred from 1993–2010 among mothers residing in ten large Massachusetts cities. The ten cities, identified from the maternal city of residence field on the birth certificate, were those with the greatest numbers of births in 2013 (most recent year of data available at the time of the study proposal): Boston, Worcester, Springfield, Lowell, Cambridge, New Bedford, Brockton, Quincy, Lynn, and Lawrence (Figure 1-1). Since the focus was on heat exposure, the final analysis included births that occurred during the warm season, designated as May 1 through September 30 (Appendix 1B) (Basu et al. 2010; Madrigano et al. 2013). Preterm birth was defined as gestational age at delivery of 20 to 36 weeks inclusive, derived from the clinical estimate of gestational age on the birth certificate (Lajinian et al. 1997; Basu et al. 2010; Wang et al. 2013; MDPH 2014).

Exposure

City-specific data on meteorological measures including daily maximum ambient temperature and heat index were provided by Dr. Mathew Barlow, PhD, and Dr. Laurie Agel, PhD from the Department of Environmental, Earth, and Atmospheric Sciences at the University of Massachusetts, Lowell. Heat index (HI) is a measure that takes into account temperature and relative humidity to better represent the physical experience of heat (Steadman 1984; Robinson 2001; Anderson and Bell 2011; Madrigano et al. 2013).

To calculate HI, a National Weather Service (NWS) formula was used (Appendix 1A). A detailed description of temperature and HI measures is available in Appendix 1A.

For exposure, each mother was assigned daily maximum ambient temperature and HI values for her city of residence. Five definitions of heat wave were used (Table 1-1). The first four definitions (HW1-4) were two or more consecutive days of maximum heat index exceeding the 85th, 90th, 95th and 98th percentiles, respectively, of warm season values for a given city. A fifth definition of heat wave (HW5) based on absolute ambient temperature values from the NWS "official" heat wave definition was also used — three or more consecutive days with the temperature reaching or exceeding 90ºF (NWS1). There is a lack of consensus on the definition of heat wave, but this approach of using HI and examining multiple thresholds for each community is consistent with the NWS and previous studies (Robinson 2001; Anderson and Bell 2011; Hattis et al. 2012; Wang et al. 2013; NW2). Also, using multiple definitions based on absolute and relative measures provides a richer and more complete look at the impact of extreme heat.

Study Design

This study used a case-crossover design in which each case served as her own control. This design automatically matches cases and controls on factors that do not change within individuals (i.e., time-fixed) (Rothman et al. 2008). The risk period was the seven days prior to delivery, inclusive of the delivery day, as has been defined in prior studies (Lajinian et al. 1997; Lee et al. 2008; Basu et al. 2010; Auger et al. 2014; Basu et al. 2017; Ha et al. 2017). We used symmetric, bi-directional selection of referent periods within a short time of the risk period, which has been shown to limit the influence of seasonal and long-term time trends (Bateson and Schwartz 1999). Two seven-day referent periods on either side of the risk window were selected (four total), each of which had the same distribution of days of the week as the risk period, ending with the same day of the week as the delivery day (Figure 1-2). Post-outcome periods can be included as reference periods as long as the occurrence of the outcome does not affect subsequent probability of exposure, which is generally true for environmental, as opposed to behavioral, exposures (Bateson and Schwartz 1999; Levy et al. 2001). This is important because the purpose of the control group is to represent the exposure prevalence in the source population and, as such, selection of controls should not be related to exposure (Rothman et al. 2008).

Covariables

Information on potential covariables, including maternal age, maternal race/ethnicity, maternal marital status, sex of the child, and parity was obtained from the birth certificate data.

Analytic Approach

Descriptive and stratified analyses were performed to assess missing data and describe the exposure distribution and study population. For exposure, percentiles of warm-season temperatures for each city were estimated in order to identify heat waves according to the various thresholds described above. For the purpose of describing the study population, the distribution by maternal demographics, gestational age, sex of child, month and year of birth, and parity was examined.

Since data from case-crossover studies are matched-pair case-control data, we used a matched analysis to evaluate the associations of interest (Rothman et al. 2008). We used conditional logistic regression to calculate odds ratios and 95% confidence intervals for the association of heat wave (yes/no) and the log(odds) of preterm birth (yes/no) with a stratum for each woman. Odds ratios were also generated through assessment of discordant pairs (Appendix 1C) (Greenland 2008). In addition to the analysis for all preterm births, the association of heat wave with various gestational ages was evaluated since risk factors for preterm birth may vary by gestational age: 20–27 weeks (early preterm), 28–33 weeks (moderately preterm), and 34–36 weeks (late preterm) (Institute of Medicine 2007; Strand et al. 2012; Schifano et al. 2013; MDPH 2014). Also, because certain subgroups may be more susceptible, effect modification on a relative scale by select factors, including month of delivery (May/June; July/August/September), maternal age group (<20; 20–29; 30–39; 40–54 years) and maternal race/ethnicity (Hispanic; White non-Hispanic; Black non-Hispanic; Other non-Hispanic) was assessed (Goldenberg et al. 2008; Basu et al. 2010; Dadvand et al. 2011; Schifano et al. 2013; Basu et al. 2017).

Sensitivity Analyses

A sensitivity analysis was conducted to examine the potential impact of varying the referent period (Levy et al. 2001). We accomplished this by examining the effect with each of the four weeks included in the overall reference period as an individual referent period. This same analysis was repeated stratifying by delivery month.

Results

Overall, there were 404,655 births (average 22,480 per year) in the ten cities from 1993–2010. Of those, 9.1% were preterm, most of which (79.6%) were singleton births. Of those, the 12,382 (42.4%) that occurred from May through September comprised the population for analysis.

Table 1-2 presents the characteristics of this population. The majority (69.7%) of the births were late preterm, 22.1% moderately preterm and 8.2% were early preterm. Just over half of the births (54.5%) were male, nearly half of mothers (47.0%) were aged 20–29 years, 35.0% were White, non-Hispanic, 27.1% Black, non-Hispanic, and 27.2% Hispanic. Boston was the most common city of residence among mothers (38.2%), followed by Springfield (13.2%) and Worcester (10.1%).

Select temperature measures by city are presented in Table 1-3. As expected, heat index values were higher on average than ambient temperature values for all cities and the maximum values of the ranges were also higher. For both HI and ambient temperature, Springfield had the highest average values and Worcester the lowest. In terms of the thresholds for determining heat wave days based on percentiles of warm season temperatures, Worcester consistently had the lowest value and the city with the highest value varied by percentile.

The number of days reaching and/or exceeding each temperature-based threshold, along with the number of heat waves by definition are presented by city in Table 1-4. Within each city, as expected, the number of days meeting the respective heat index-based threshold decreased from the 85th to 98th percentiles, ranging from 407–415 days meeting the 85th percentile threshold to 52–55 meeting the 98th. The same was true for the corresponding number of percentile-based heatwaves (HW1 to HW4). The number of heat waves meeting the HW1 definition ranged from 93–106 across cities and the number meeting the HW4 definition ranged from 5–27. The number of days with maximum ambient temperatures ≥ 90ºF as well as the number of heat waves meeting HW5 definition varied more across the study cities, ranging from 44–166 and 5–20, respectively.

Figures 1-3a and 1-3b shows results from conditional logistic regression for the short-term effect of heat wave on preterm birth. Odds ratios (OR) and corresponding 95% confidence intervals (CI) are presented by heat wave definition overall, and by gestational age, delivery month period, maternal age and maternal race/ethnicity. Additional results are presented in Appendix 1D. The overall results show, across heat wave definitions, little to no association with preterm birth. The odds ratios for HW1, HW2 and HW3 were positive, whereas those for HW4 and HW5 were less than 1.0, although all were close to the null. Results were similar for late preterm birth, but varied for early and moderately preterm birth. Although estimates were imprecise, findings suggest potential increases in risk for birth at earlier gestational ages during less extreme heat waves (HW1, HW2, HW3). By delivery month, there appeared to be a reduction in risk during May/June with the HW4 and HW5 definitions of heat wave (OR= 0.63 and 0.74, respectively). Among women in the oldest age group (40–54 years), odds ratios were all less than 1.0 indicating decreased risk across heat wave definitions, although estimates were imprecise. Women aged 30–39 years old had 1.14 (95% CI 1.05–1.24) and 1.15 (95% CI 0.97–1.37) times the odds of preterm birth during periods meeting the HW1 and HW5 definitions, respectively. Hispanic women had 1.16 (95% CI 1.02–1.33) and White, non-Hispanic women 1.15 (95% CI 0.95–1.38) times the odds during periods meeting the HW3 and HW5 definitions, respectively.

Sensitivity Analyses

Table 1-5 presents the results of the sensitivity analysis using conditional logistic regression to estimate odds ratios and corresponding 95% confidence intervals comparing the index period to each of four 1-week referent periods. Overall, results from this analysis did not differ from that of the main analysis or change the overall conclusion.

Table 1-6 shows results of a sensitivity analysis using the HW5 definition to examine the findings by delivery month more closely. The results indicate that during both periods examined, there were differences in the measure of effect depending on which week is used as the referent period. However, the patterns for each period were opposite. During May/June, odds ratios decreased from referent week 1 (OR=2.31) to week 4 (OR=0.38). In contrast, odds ratios increased across referent weeks during July/August/September from 0.88 using week 1 as the reference to 1.48 using week 4.

Discussion

This study estimated the short-term effect of maternal exposure to heat wave on preterm birth among residents of ten Massachusetts cities from 1993–2010 using five definitions of heat wave. Across heat wave definitions, overall findings suggested little to no association. Some point estimates indicated an increased risk and some a decreased risk of preterm birth during heat waves, but all were close to the null.

While several recent studies have found a positive short-term association between heat and preterm birth (Basu et al. 2010; Cox et al. 2016; He et al. 2016; Ha et al. 2017; Mathew et al. 2017; Basu et al. 2017), others have failed to support an association (Porter et al. 1999; Lee et al. 2008; Wolf et al. 2012; Auger et al. 2014; Vicedo-Cabrera et al. 2015). A study by Kloog et al. (2015) in Massachusetts produced inconsistent results leading to differing conclusions depending on method of temperature exposure measurement. The authors noted the need for additional studies to further explore the relationship.

Among the few prior studies that evaluated heat wave exposure specifically, there were variations in heat wave definitions, exposure windows and geographic location, making it challenging to directly compare findings with those of the current study. A case-crossover study in Alabama by Kent et al. (2014) found some positive and some negative estimates of the short-term effect of heat wave on preterm birth across fifteen heat wave definitions, with most estimates falling close to 1.0. A survival analysis in Australia by Wang et al. (2013) using nine heat wave definitions found hazard ratios ranging from 1.13 to 2.0 for the association in the "last gestational weeks before delivery". The authors did not further define the exposure window, making results somewhat difficult to interpret. Finally, Schifano et al. (2013) found an increased short-term effect on preterm birth only with heat waves occurring in cooler months of the warm season in Rome, Italy.

In this study, we hypothesized that the effect would be greater among women later in pregnancy based on prior evidence suggesting that the effect of heat is particularly important during gestational weeks corresponding to later preterm (Schifano et al. 2013; Strand et al. 2012). Schifano et al. (2013) found increased risk among births occurring after the 32nd week of gestation, while Strand et al. (2012) observed an increased risk from the 28th to 36th gestational week, but not earlier. However, our findings suggested little effect on late preterm births in our study population, and possible effects on early and moderately preterm births with less severe definitions of heat wave. These findings should be further evaluated in future studies and underscore the importance of examining subgroups of gestational age rather than solely a dichotomous preterm birth outcome.

Effect measure modification by groupings of delivery month, maternal age, and maternal race/ethnicity was assessed. Interestingly, with the most extreme definitions of heat wave (HW4 and HW5), lower odds of preterm birth during May/June were found. This was somewhat surprising considering that we would expect women to be less acclimatized in these early ‘cooler’ months, and thus for heat waves to perhaps have a greater impact compared to later in the season (Basu et al. 2010; Schifano et al. 2013). However, perhaps the findings reflect women changing behavior to avoid the unusually warm weather so early in the season. This rationale is consistent with that of Vicedo-Cabrera (2015) regarding their study in Stockholm, Sweden. The authors reasoned that their findings of an association of preterm birth with moderate, but not extreme, heat in the weeks preceding birth might be due to people spending more time outdoors when the temperatures are not unusually high.

In the current study, the findings by delivery month were explored in more depth with a sensitivity analysis varying reference periods. Results suggested that selection bias could occur with improper choice of reference period in this type of study. The purpose of the reference group (or time period) in a case-control study is to represent the exposure distribution in the source population that gave rise to the cases (Rothman et al. 2008). We posit that this study achieved this by using symmetric, bidirectional selection of reference periods within a short time of the risk period (Bateson and Schwartz 1999). As results in Table 1-6 suggest, however, if unidirectional selection of reference periods had been used, bias may have been introduced. If referent periods were chosen only from weeks prior to the risk period, then the effect estimate may be biased upward during May/June and downward during July/August/September. Conversely, if only the weeks following the risk period were used as reference, the estimate may be biased downward for the early months and upward for the later months.

Based on prior evidence in the literature, this study hypothesized that certain subpopulations of women, namely those who were younger and non-White, would be particularly vulnerable to the effect of heat waves (Basu et al. 2010; Schifano et al. 2013; Basu et al. 2017). However, minor observed differences across categories and heat wave definitions were difficult to interpret. By age, women in the oldest age category (40–54 years) consistently had the lowest odds across definitions, although estimates were imprecise. Women aged 30–39 years had higher odds of preterm birth with the least extreme definition of heat wave (HW1) as well as with one of the most extreme (HW5). Other studies have reported varying effects of heat on preterm birth by maternal age, with older women experiencing a weaker effect. Two studies by Basu et al. (2010, 2017) found the effect of temperature on preterm birth to be strongest among young mothers less than 20 years old, and that it decreased with increasing age, with mothers aged ≥35 years having the lowest risk. Schifano et al. (2013) also found a weaker effect among women in the oldest age group examined (≥37 years). The authors suggested that older women may be followed more closely by health care providers, and therefore might take more precautions against the heat.

By race/ethnicity, Hispanic women in the current study had 16% higher odds of preterm birth during heat waves meeting the HW3 definition compared to the reference period, and White, non-Hispanic women had 15% higher odds during heat waves meeting the HW5 definition. Not all previous studies evaluated differences in the effect by race/ethnicity, and measures used have varied. Findings from Basu et al. (2010) in California, whose measure of race/ethnicity was comparable to that of the current study, revealed the strongest associations among non-Hispanic Black and Asian mothers. A more recent study by Basu et al. (2017) reported greater effects of temperature on preterm delivery among Black and Hispanic mothers compared to Asian and White mothers. Potential effect modification by race/ethnicity should be considered in future studies examining the effect of heat on preterm birth.

Strengths of this study included a large study sample size, enabling evaluation of the effect within various gestational age categories and by potential modifiers. Symmetric bi-directional selection of referent periods (Bateson and Schwartz 1999) within a short time of the risk window (i.e., within weeks in the same year) limited the influence of long-term time trends and seasonality (Levy et al. 2001). Lastly, this study examined the effect using five definitions of heat wave based on both heat index and ambient temperature measures.

This study had several limitations. First, there was a possibility of inaccurate reporting of the clinical estimate of gestational age in the birth certificate data (Wier et al. 2007; Martin 2007). Despite this concern, research has shown that the clinical estimate is a more valid measure of gestational age compared with the measure based on the date last normal menstrual period began, and MDPH has routinely published this as the state's standard measure in annual reports (Lynch et al. 2007; Wier et al. 2007; Callaghan et al. 2010; Barradas et al. 2014; Dietz et al. 2014; MDPH 2014; Martin et al. 2015).

There was also potential for misclassification of exposure due to the city-level assignment of temperature or heat index and/or error in the actual measurements. We would expect such misclassification to likely be nondifferential. Also in terms of exposure, although we did evaluate the effect using multiple definitions of heat wave, it is possible that there was another definition not included with which we might have seen a stronger effect. Kent et al. (2014) used fifteen definitions and found significant effects on preterm birth risk with just three definitions. Wang et al. (2013) also found some variability in effect estimates by heat wave definition. Finally, it is possible that the one-week exposure window in this study was too short to see an effect. However, this window was chosen based on evidence from previous studies supporting a short-term effect of heat on preterm birth (Basu et al. 2010; Dadvand et al. 2011; Schifano et al. 2013).

Next, we lacked information on air conditioning use and indoor air temperature, which may have modified or mediated the effect. We also did not include measures of air pollution. Published findings on the impact of various air pollutants on the association between temperature and preterm birth are inconsistent (Lee et al. 2008; Basu et al. 2010; Schifano et al. 2013; Wang et al. 2013). We considered air pollution to be a mediator on the causal pathway and, since we were not able to evaluate direct and indirect paths, the observed findings represent the total effect of heat wave on preterm birth (Reid et al. 2012; Wolf et al. 2012; Buckley et al. 2014).

Next, the Massachusetts birth registry dataset includes only live births. By not including stillbirths in our study, we might have underestimated the actual burden of preterm birth. Restricting to live births may have made our study population slightly less representative, and might also have introduced bias. However, we anticipate that the effect of this bias would be small, since stillbirths comprise only about 5% of preterm births in developed countries (Blencowe et al. 2013). Furthermore, since we excluded multiple pregnancies (e.g., twins, triplets, etc.), a risk factor for stillbirth, from our analysis by design, the percentage of stillbirths in our eligible population was likely lower than 5%.

Finally, preterm birth was chosen as the outcome in this study due to the potentially serious health sequelae. However, the possibility that heat could also be a trigger for term births was not considered. Auger et al. (2014) found an association between heat and early term birth (37–38 gestational weeks), but not with preterm birth in Montreal, Canada. More recently, in the U.S., Ha et al. (2017) reported elevated short-term risk of early term birth with increased temperature during the warm season. By limiting this study to preterm birth, an important effect of heat waves on pregnancies in Massachusetts may have been missed. This should be evaluated in future studies.

In conclusion, overall findings from this study failed to support our hypothesis of increased short-term risk of preterm birth during heat wave compared to non-heat wave periods among pregnant women in Massachusetts. However, stratified analyses revealed potential increases in risk at earlier gestational ages at less extreme levels of heat which should be explored in future studies.

Figure 1-1. Massachusetts map showing the locations of the ten study cities

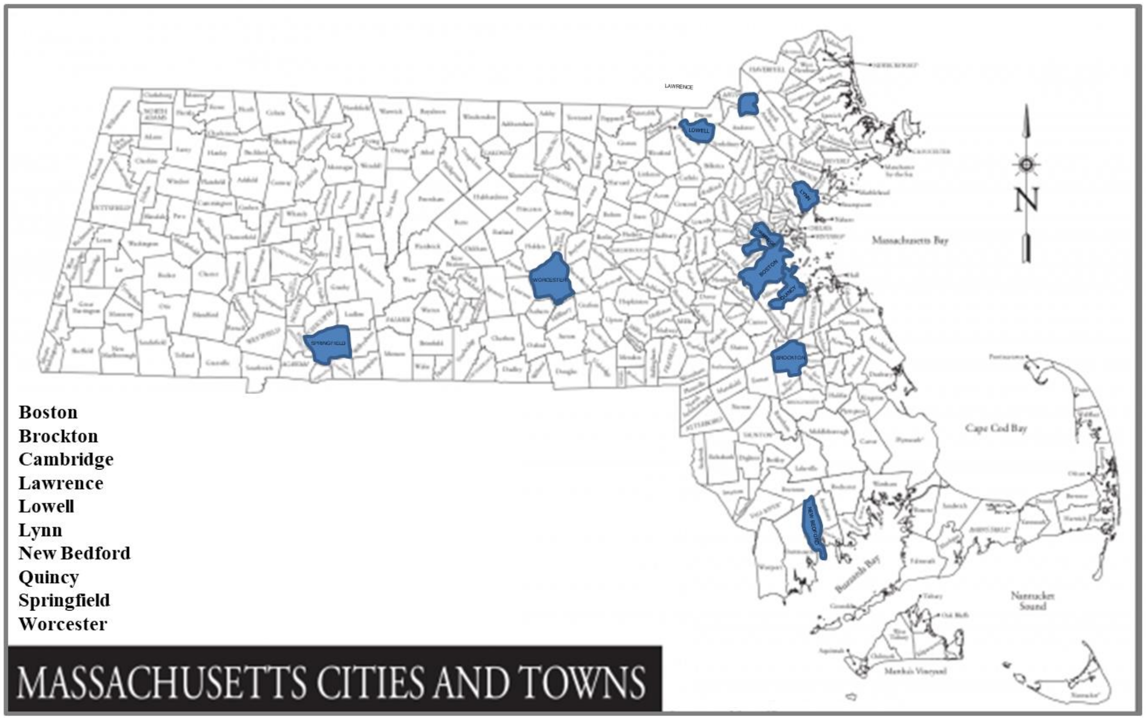

Figure 1-2. Symmetric bi-directional referent selection

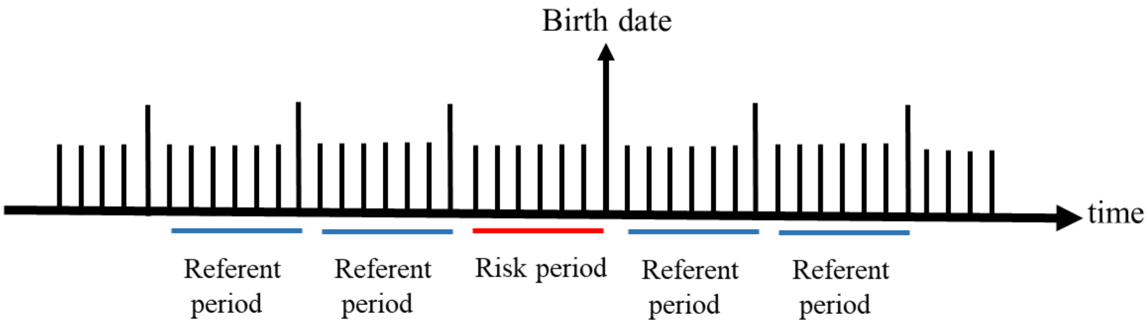

Table 1-1. Heat wave definitions

HW1: ≥2 consecutive days with maximum HI (ºF) > 85th percentile of warm season (May–Sept) HI for a given city
HW2: ≥2 consecutive days with maximum HI (ºF) > 90th percentile of warm season (May–Sept) HI for a given city
HW3: ≥2 consecutive days with maximum HI (ºF) > 95th percentile of warm season (May–Sept) HI for a given city
HW4: ≥2 consecutive days with maximum HI (ºF) > 98th percentile of warm season (May–Sept) HI for a given city
HW5: ≥3 consecutive days with maximum ambient temperature ≥ 90 ºF.

NOTE: HI=Heat Index

Table 1-2. Characteristics of preterm singleton births, May–September, ten study cities, Massachusetts, 1993–2010.

	Preterm Singleton Births (N=12,382)	
Characteristic	#	%
Gestational Age		
Early Preterm (20–27 weeks)	1014	8.2
Moderately Preterm (28–33 weeks)	2735	22.1
Late Preterm (34–36 weeks)	8633	69.7
Month of Birth		
May	2531	20.4
June	2506	20.2
July	2592	20.9
August	2486	20.1
September	2267	18.3
Year of birth		
1993	789	6.4
1994	773	6.2
1995	749	6.1
1996	627	5.1
1997	640	5.2
1998	613	5.0
1999	660	5.3
2000	684	5.5
2001	681	5.5
2002	696	5.6
2003	671	5.4
2004	708	5.7
2005	686	5.5
2006	732	5.9
2007	733	5.9
2008	688	5.6
2009	638	5.2
2010	614	5.0

Table 1-2 (cont.)

Characteristic	Preterm Singleton Births (N=12,382) #	%
Maternal city of residence		
Boston	4734	38.2
Brockton	911	7.4
Cambridge	439	3.6
Lawrence	756	6.1
Lowell	900	7.3
Lynn	736	5.9
New Bedford	531	4.3
Quincy	496	4.0
Springfield	1634	13.2
Worcester	1245	10.1
Sex of child*		
Male	6752	54.5
Maternal Age		
<20	1704	13.8
20–29	5814	47.0
30–39	4435	35.8
40–54	429	3.5
Marital Status		
Not married	6926	55.9
Maternal Race/Ethnicity**		
Hispanic	3349	27.2
White, Non-Hispanic	4318	35.0
Black, Non-Hispanic	3339	27.1
Other, Non-Hispanic	1329	10.8
Parity***		
1	5830	47.2
2	3232	26.1
3	1787	14.5
4	866	7.0
5 or more	649	5.2

*   n=1 record missing sex of child

** n=47 records missing race and/or ethnicity

***n=18 records missing parity

Table 1-3. Select temperature and heat index (HI) values by Massachusetts city, 1993–2010.

	Maximum daily ambient temperature (ºF): April–October			Maximum daily HI (ºF): April – October			Thresholds based on percentiles of warm season HI for a given city (ºF)			
City	Average	Range		Average	Range		85th	90th	95th	98th
Boston	71.93	34.70	97.70	74.36	34.70	131.27	93.36	97.52	103.81	110.36
Brockton	71.84	35.60	97.70	74.26	35.60	131.27	92.75	96.81	102.81	109.32
Cambridge	72.20	34.70	98.60	74.63	34.70	129.31	93.36	97.72	103.93	110.96
Lawrence	72.19	32.90	97.70	74.50	32.90	127.87	93.23	96.81	103.34	110.52
Lowell	72.49	32.00	98.60	74.85	32.00	128.17	93.97	97.6	103.53	110.68
Lynn	71.38	34.70	97.70	73.69	34.70	128.85	92.59	96.52	103.08	109.6
New Bedford	71.17	36.50	97.70	73.21	36.50	130.25	89.95	93.36	98.42	104.44
Quincy	71.80	35.60	97.70	74.22	35.60	131.27	93.34	97.17	103.53	109.9
Springfield	73.04	33.80	98.60	75.50	33.80	130.45	93.76	97.31	103.98	109.81
Worcester	69.80	31.10	95.00	71.29	31.10	118.21	87.76	90.44	95.76	102.16

Table 1-4. Number of days reaching and/or exceeding respective heat index (HI) or temperature threshold and number of heat waves by definition and Massachusetts city, 1993–2010.

	Number of days ≥ respective HI or temperature threshold					Number of heat waves by definition				
City	85th percentile	90th percentile	95th percentile	98th percentile	90ºF	HW1	HW2	HW3	HW4	HW5
Boston	415	276	137	55	143	102	72	39	15	18
Brockton	414	276	137	55	114	93	74	35	17	16
Cambridge	415	276	137	55	154	100	69	37	16	20
Lawrence	412	276	137	54	155	105	72	39	16	19
Lowell	412	269	137	54	166	106	68	37	13	18
Lynn	414	276	137	55	129	100	75	39	16	16
New Bedford	407	275	137	55	51	93	61	35	15	9
Quincy	411	271	137	52	135	97	69	38	16	18
Springfield	414	276	134	53	166	102	73	37	15	27
Worcester	409	277	133	52	44	97	68	34	14	5

Figure 1-3a. Odds ratios (OR) and 95% confidence intervals (CI) for the short-term association between heat wave (HW1-5) and preterm birth overall and by gestational age and month.

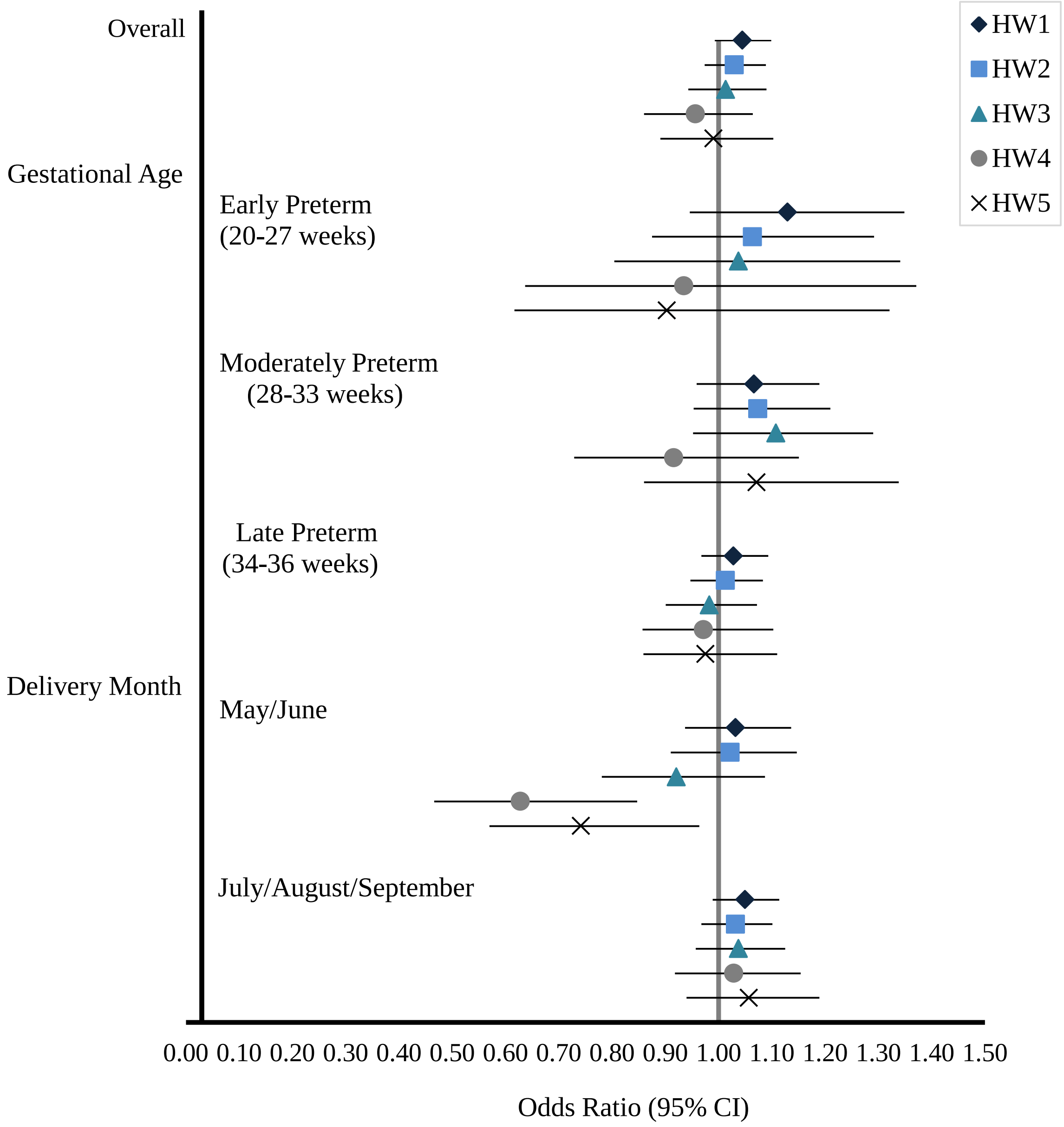

Figure 1-3b. Odds ratios (OR) and 95% confidence intervals (CI) for the short-term association between heat wave (HW1-5) and preterm birth by maternal age and race/ethnicity.

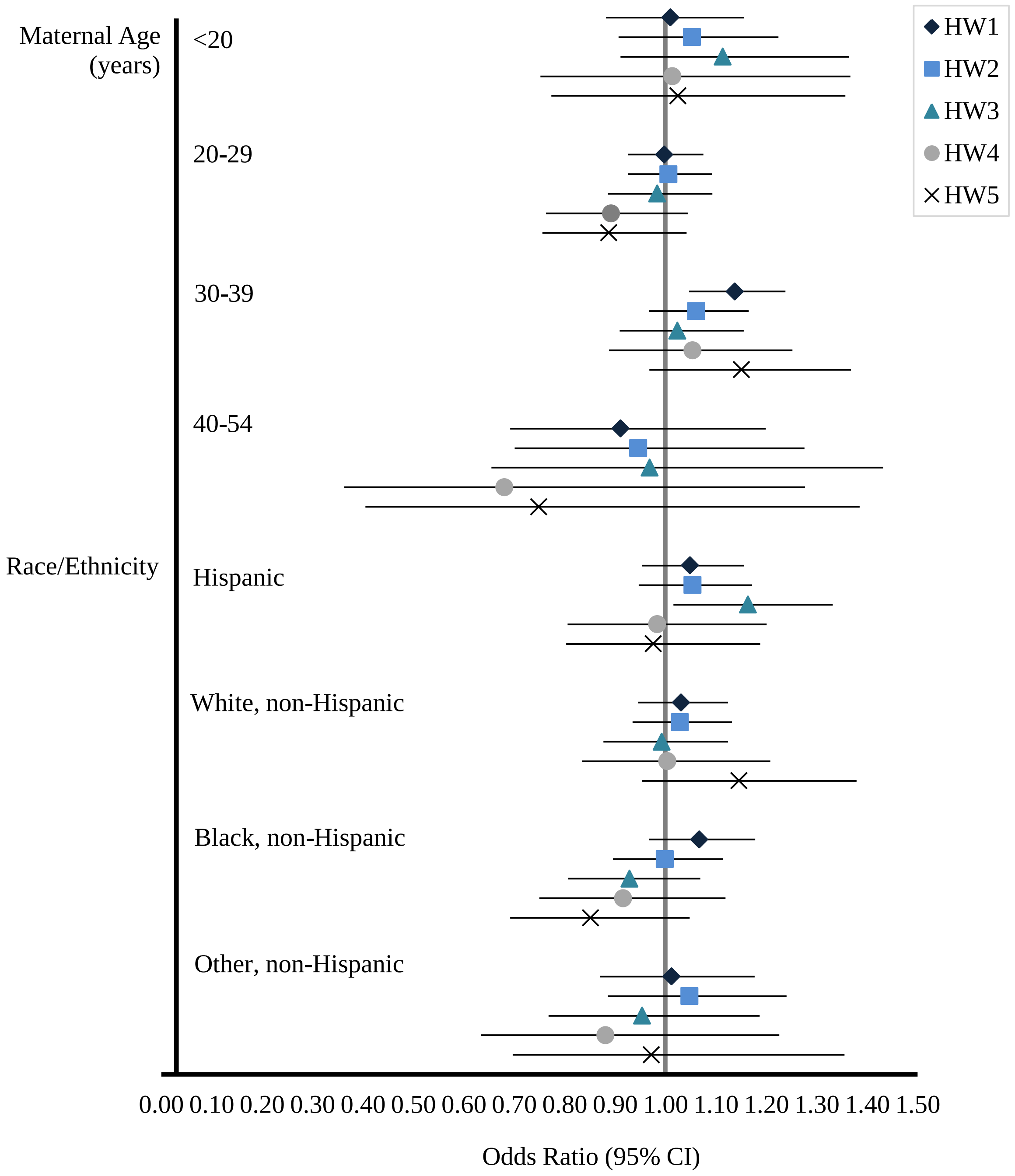

Table 1-5. Odds ratios (OR) and 95% confidence intervals (CI) from sensitivity analysis varying the reference period by heat wave definition (HW1-5).

	HW1			HW2			HW3			HW4			HW5		
Reference period	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
1	1.03	0.97	1.10	1.02	0.95	1.09	1.02	0.93	1.12	0.98	0.86	1.13	0.98	0.86	1.12
2	1.06	0.99	1.13	1.02	0.95	1.10	1.03	0.94	1.13	0.92	0.80	1.05	1.04	0.91	1.20
3	1.04	0.98	1.12	1.02	0.95	1.10	0.98	0.90	1.08	0.95	0.83	1.08	0.94	0.82	1.07
4	1.05	0.99	1.12	1.05	0.98	1.13	1.03	0.93	1.12	0.99	0.86	1.13	1.01	0.88	1.16
All	1.05	0.99	1.10	1.03	0.97	1.09	1.01	0.94	1.09	0.96	0.86	1.06	0.99	0.89	1.10

Note: Reference period 1 is two weeks prior to the risk period, 2 is the week immediately prior to the risk period, 3 is the week immediately following the risk period and 4 is two weeks after the risk period.

Table 1-6: Odds ratios (OR) and 95% confidence intervals (CI) from sensitivity analysis varying reference period (HW5 definition only) by delivery month.

	May/June			July/Aug/Sept		
Reference period	OR	95% CI		OR	95% CI	
1	2.31	1.49	3.57	0.88	0.76	1.02
2	1.72	1.16	2.55	0.97	0.84	1.13
3	0.57	0.42	0.77	1.06	0.91	1.23
4	0.38	0.28	0.50	1.48	1.26	1.74
All	0.74	0.57	0.96	1.06	0.94	1.19

Note: Reference period 1 is two weeks prior to the risk period, 2 is the week immediately prior to the risk period, 3 is the week immediately following the risk period and 4 is two weeks after the risk period.

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STUDY 2: EVALUATING THE SHORT-TERM EFFECT OF HEAT WAVE EXPOSURE ON PEDIATRIC ASTHMA MORBIDITY IN MASSACHUSETTS

Introduction

Asthma is a common pediatric chronic respiratory disease characterized by episodic wheezing, breathlessness, chest tightness, and coughing (USHHS 2018). Approximately 8% of U.S. children aged 0–17 years have asthma, with an estimated 150,000 children (12%) affected in the state of Massachusetts alone (MDPH 2017a; Zahran et al. 2018). Those who are male, Hispanic, and non-Hispanic Black are disproportionately impacted (MDPH 2017a; MDPH 2017b; Zahran et al. 2018). In addition to the health and financial burden of pediatric asthma, it is associated with missed school days for children and work absences for parents (Wang et al. 2005; MDPH 2017b; Zahran et al. 2018).

The burden of respiratory disease is expected to increase with climate change (Confalonieri et al. 2007; Pinkerton et al. 2012; Rice et al. 2014). Across the United States, average annual temperature as well as the frequency and intensity of extreme heat events are projected to rise over the coming decades (Vose et al. 2017). Northern regions, including the northeast, will likely experience larger temperature increases than southern regions (Vose et al. 2017). Warmer temperatures may impact respiratory health directly and indirectly via increased dust, pollen production, and air pollution (Aitken et al. 1985; Confalonieri et al. 2007; Mireku et al. 2009; Hayes et al. 2012; Pinkerton et al. 2012; Rice et al. 2014). Children may be particularly vulnerable since, compared to adults, they breathe more air per unit body weight and tend to spend more time outdoors (Bearer 1995; Sheffield and Landrigan 2011).

The impact of extreme heat events, or heat waves, on pediatric asthma has not been well studied. Prior research has demonstrated increased risk of morbidity and mortality among children during heat waves (Leonardi et al. 2006; Knowlton et al. 2009; Nitschke et al. 2011; Xu et al. 2013; Xiao et al. 2017). However, findings for respiratory disease have been inconsistent (Nitschke et al. 2011), and few studies have reported specifically on asthma as an outcome (Xu et al. 2013; Winquist et al. 2016; O'Lenick et al. 2017). Two recent studies in Atlanta, Georgia (Winquist et al. 2016; O'Lenick et al. 2107) found an association between daily maximum temperature and pediatric emergency department (ED) visits for asthma or wheeze, but did not specifically look at the impact of heat waves as a temperature metric. Findings from a study by Xu et al. (2014) suggested an added effect of heat wave to that of high temperatures on pediatric ED admissions for chronic lower respiratory disease, predominantly asthma, in Brisbane, Australia.

The study described here aimed to assess the impact of heat waves on asthma morbidity among children in Massachusetts. Specifically, the objectives were to: 1) examine the effect of heat waves on pediatric asthma-related emergency department (ED) visits, 2) evaluate effect measure modification by select demographic factors, and 3) assess how the effect varied by heat wave definition, which could be important for specifying regional heat wave metrics for use in public health planning. The primary hypothesis evaluated was that among children aged 0–17 years, the ED visit rate for asthma would be higher during heat waves compared to reference periods, and that the effect would be greater among children who were young (aged 0–4 years) (Kovats et al.

2004; Xu et al. 2013), male (Xu et al. 2013; O’Lenick et al. 2017), and non-White (O’Lenick et al. 2017). Cumulative effects within 1–3 days of the end of the heat wave were assessed as previous studies have reported increased morbidity in the days following extreme heat exposure (Ye et al. 2012; Winquist et al. 2016; O’Lenick et al. 2017; Xiao et al. 2017). The study also evaluated pediatric ED visits for all diagnoses and overall respiratory disease to enable better comparison with findings from prior studies, and those for heat illness as a validation measure, since these were expected to increase during heat waves (Knowlton et al. 2009; Nitschke et al. 2011; O’Lenick et al. 2017).

Methods

Outcome

Data on ED visits from all acute care hospitals in Massachusetts for the years 2005–2014 were obtained from the Center for Health Information and Analysis Case Mix data via the Massachusetts Department of Public Health. The Case Mix data includes three mutually exclusive data sets: ED discharges, outpatient observation stays (OOS) and inpatient hospitalizations (IH) (CHIA 2016). In order to capture all eligible ED visits, all records from the ED discharge data set as well as those OOS or IH that came in through the ED were included in this study. The study population consisted of residents aged 0–17 years within ten large Massachusetts cities: Boston, Brockton, Cambridge, Lawrence, Lowell, Lynn, New Bedford, Quincy, Springfield, and Worcester. The ten cities, identified from the city of residence field in the ED visit data, are among the largest in Massachusetts (Figure 1-1). In 2010, the midpoint of the study period, an estimated 329,000 children aged 0–17 years, or 23% of the Massachusetts total, resided in the ten study cities (ACS 2010).

Outcomes of interest were identified using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9) codes in the primary discharge diagnosis field, and included ED visits for any cause; asthma/wheeze (493, 786.07); respiratory disease (460-466, 477, 480-486, 491-493, 496, 786.07); and heat illness (992) (Winquist et al. 2016; O'Lenick et al. 2017). A list of outcomes with specific ICD-9 codes and corresponding descriptions are presented in Table 2-1. Since the focus was on heat exposure, the final analysis only included ED visits that occurred during the 'warm season' of May 1 – September 30 (Basu et al. 2010; Madrigano et al. 2013).

Exposure

Data on meteorological measures including daily maximum ambient temperature and heat index for the ten study cities were provided by Drs. Laurie Agel and Mathew Barlow in the Department of Environmental, Earth, and Atmospheric Sciences at the University of Massachusetts, Lowell. Heat index (HI) is a measure that takes into account temperature and relative humidity to better represent the physical experience of heat (Steadman 1984; Robinson 2001; Anderson and Bell 2011; Madrigano et al. 2013). To calculate HI, a National Weather Service (NWS) formula was used (Appendix 1A). A detailed description of ambient temperature and HI measures is available in Appendix 1A.

For exposure, two definitions of heat wave were used. The first (T90 definition) was the NWS "official" heat wave definition based on absolute ambient temperature values — three or more consecutive days with the temperature reaching or exceeding

90ºF (NWS1). For the second definition (P95 definition), we estimated the 95th percentile of warm-season maximum heat index values for each city during the study period. A heat wave was then characterized as two or more consecutive days with maximum heat index exceeding the 95th percentile of warm season values for a given city during the study period. There is no universal definition of heat wave, but this approach of using multiple definitions for each community is consistent with the NWS and previous studies on the health effects of extreme heat events (Robinson 2001; Anderson and Bell 2011; Wang et al. 2013; Hattis et al. 2012; NWS2).

For each heat wave (exposed) period included in the study, an unexposed reference period of equal length and distribution of days of the week within the same year, season and city was identified (Knowlton et al. 2009). No reference day met the respective criteria for a heat wave day (i.e., all were unexposed). Ideally, the unexposed reference period was chosen in the week before the heat wave period. If that was not possible (e.g., one day reached the heat wave threshold), a qualifying period in the two weeks prior or two weeks following the heat wave period was used. We also evaluated the effect for 1–3 days following the heat wave period since prior studies found increases in respiratory morbidity in the days following exposure to high temperature (Winquist et al. 2016; O'Lenick et al. 2017). All 'lag days' were unexposed in that they did not meet the respective criteria for a heat wave day. The July 4th holiday was not included in any heat wave, reference, or lag periods. The actual dates of T90 and P95 heat waves and corresponding reference periods included in analyses are presented in Appendix 2A and 2B, respectively.

Covariables

Information on age, sex, and race/ethnicity was obtained from the Case Mix ED visit data.

Analytic Approach

Descriptive and stratified analyses were performed to assess missing data and describe the exposure and outcome distributions. For the purpose of describing the study population, the distribution of ED visits by month and year of visit, city of residence, age group, sex, and race/ethnicity was examined.

Rate ratios were generated by dividing the count of ED visits within the exposed period by the count in the reference period. Since each exposed and corresponding reference period had the same numbers of days and were chosen within the same year and season (within a couple weeks), the population size would not be expected to differ between them. Therefore, the denominators for the rates fall out of the equation and the counts were divided to obtain the rate ratio (Knowlton et al. 2009). Poisson regression was used to estimate rate ratios and corresponding 95% confidence intervals. Excess numbers of visits were also calculated by subtracting the number of visits during reference days from the number during heat wave days (Knowlton et al. 2009). Because certain subgroups of children may be more susceptible, effect measure modification by age (0–4; 5–17 years), sex (male; female), and race/ethnicity (Hispanic; White non-Hispanic; Black non-Hispanic; Other non-Hispanic) was assessed (Kovats et al. 2004; Xu et al. 2013; O’Lenick et al. 2017).

Secondary Analysis

A 'statewide' analysis was conducted using ED visit data for all Massachusetts residents aged 0–17 years with the goal of increasing statistical power. Because temperature data were only available for the ten cities noted above, it was assumed that if a heat wave definition was met for all ten cities, it would apply to the entire state. Corresponding unexposed reference days were chosen for each heat wave as described above. As in the ten-cities analyses, we also assessed the effect for up to three days following the heat wave.

Sensitivity Analysis

A sensitivity analysis was conducted to assess the extent to which including only primary discharge diagnosis may have impacted the findings. The main ten-cities analyses for asthma/wheeze and heat illness were repeated allowing for the diagnosis codes of interest to be in any of the six diagnostic fields available in the ED visit data.

Results

Overall, there were 644,108 ED visits among children from the ten cities during the warm season 2005–2014 (Table 2-2). The number ranged from a low of 59,912 in 2005 to a high of 72,399 in 2009, and averaged 64,410 per year over the ten years. Of those, 12.4% were for respiratory disease and 3.4% were for asthma/wheeze. There were 161 pediatric ED visits for heat illness during the study period. Whereas there was not much variation in the distribution of pediatric ED visits by month, the highest percentage of those for respiratory disease and asthma/wheeze occurred in May, and the highest percentage for heat illness occurred in July. The proportion of pediatric ED visits that resulted in an inpatient hospitalization or outpatient observation stay varied somewhat by outcome: 2.9% of visits for all diagnoses, 5.6% of those for respiratory disease, 11.4% of those for asthma/wheeze, and 5.0% of those for heat illness.

Table 2-2 presents the characteristics of children with ED visits during the study period. Just over half (53.4%) of all pediatric ED visits during the study period were among male children, 44.1% were among those aged 0–4 years, 36.2% among Hispanic, 26.9% among White, non-Hispanic, and 23.8% among Black, non-Hispanic children. Boston was the most common city of residence (31.4%), followed by Springfield (13.7%) and Worcester (12.0%). The characteristics of children with ED visits for respiratory disease were similar except more than half were aged 0–4 years (56.1%), and a slightly greater percentage were Black, non-Hispanic (26.4%) or Hispanic (39.9%). Among children with ED visits for asthma or wheeze, a higher percentage were male (61.4%), Back, non-Hispanic (34.5%), and from Boston (39.0%) compared to overall. Among those with ED visits for heat illness, higher percentages were aged 5–17 years (83.9%), White, non-Hispanic (39.8%), Black, non-Hispanic (31.1%), and from Brockton (14.3%) and Lowell (10.6%).

Select temperature metrics by city are presented in Table 2-3. As expected, average and maximum values were higher for HI than ambient temperature for all cities. For both HI and ambient temperature, Springfield had the highest average values and Worcester the lowest. In terms of the thresholds for determining heat wave days based on 95th percentiles of warm season temperatures, Worcester and Lynn had the lowest values, and Cambridge had the highest value. The number of days with temperatures ≥ 90ºF during the study period ranged from 23 in Worcester to 100 in Lowell. The number of days with HI values exceeding the 95th percentile of warm season values had less variability ranging from 73 in Brockton to 76 in Lowell, Lynn, New Bedford and Quincy.

The number of heat waves by definition is presented by city and year in Table 2-4. Across cities, there were fewer heat waves meeting the T90 definition compared to the P95 definition. The number meeting the T90 definition over the ten year period ranged from 2–14 across cities and the number meeting the P95 definition ranged from 18–24. The final analyses included 345 T90 and 561 P95 heat wave days with the same numbers of unexposed reference days, respectively (Appendix 2A and 2B).

Values of daily maximum temperature (Tmax) and heat index (HImax) measures for both T90 and P95 heat waves were higher than those for corresponding reference periods (Table 2-5). Also, T90 heat waves were slightly hotter, on average, than P95 heat waves. During T90 heat wave and reference days, average Tmax (ºF) was 93.0 and 81.0, respectively, and HImax (ºF) was 112.9 and 85.7, respectively. For P95 heat wave and reference days, average Tmax (ºF) was 92.2 and 80.4, respectively, and HImax (ºF) was 111.5 and 84.8, respectively.

Tables 2-6, 2-7 and 2-8 show the rate ratios (RR) and corresponding 95% confidence intervals (CI)for the effect of heat wave on pediatric ED visits for asthma/wheeze, respiratory disease, and all diagnoses, respectively. Results are presented for each diagnosis examined by ‘lag day’ overall, and by age group, sex and race/ethnicity. As shown in Tables 2-6a and 2-6b, in the ten cities, there was some evidence of a weak association between heat waves and pediatric ED visits for asthma/wheeze, although the numbers of excess visits were small (RR_{T90}=1.04, 95% CI: 0.88–1.23; RR_{P95}=1.02, 95% CI: 0.89–1.16). There was no meaningful increase in the rate of visits for respiratory disease during heat waves compared to reference periods (RR_{T90}=0.99, 95% CI: 0.92–1.07; RR_{P95}=0.96, 95% CI: 0.90–1.02) (Tables 2-7a and 2-7b). The rate of ED visits for all diagnoses (Tables 8a and 8b) increased slightly during heat waves (RR_{T90}=1.02, 95% CI: 1.00–1.05; RR_{P95}=1.01, 95% CI: 0.99–1.03), and remained elevated for three days beyond the end of the T90 heat waves (RR_{T90}=1.05, 95% CI: 1.03–1.07) and two days beyond the end of the P95 heat waves (RR_{P95}=1.04, 95% CI 1.03–1.06). In terms of excess visits, the number for T90 heat waves ranged from 288 on lag day 0 to 1,181 on lag day 3 (Table 2-8a). For P95 heat waves, the number rose from 230 on lag day 0 to 1,484 on lag day 2 (Table 2-8b). For all three outcomes, findings were generally consistent across strata of age, sex and race/ethnicity.

Findings for heat illness are shown in Table 2-9. The absolute numbers of ED visits for heat illness in the ten cities were small, particularly during reference periods, and are not presented. Excess numbers of visits at lag 0 were 36 and 48 for T90 and P95 heat waves, respectively. On a relative scale, effect estimates indicated increased rates during heat waves, but were imprecise, as evidenced by the wide confidence intervals (RR_{T90}=19.00, 95% CI: 4.58–78.76; RR_{P95}=13.00, 95% CI: 4.70–35.94).

Secondary Analysis

Nine P95 heat waves and zero T90 heat waves met the criteria for inclusion in the statewide analysis. The actual dates of heat wave days and corresponding reference days are presented in Appendix 2C. As shown in Table 2-5, the average and median values of maximum HI on heat wave days (115.7 and 114.7, respectively) were slightly higher than those for the ten-cities analysis (111.5 and 110.0, respectively), although the corresponding values for reference days were similar.

Tables 2-10a, 2-10b, and 2-10c show results from the statewide analysis for asthma/wheeze, respiratory disease, and all diagnoses, respectively. For asthma/wheeze (Table 2-10a), compared to the ten-cities analysis, the statewide analysis revealed a higher rate ratio (RR=1.14, 95% CI: 1.00–1.31), and the increase was observed for three days following the heat wave. Statewide findings suggested a greater effect among female than male children (RR_{female}=1.30, 95% CI: 1.04–1.62; RR_{male}=1.05, 95% CI: 0.88–1.26). By race/ethnicity, relative increases in rates of asthma/wheeze ED visits during heat waves were greatest among White, non-Hispanic (RR=1.27, 95% CI: 1.04–1.56) and Other, non-Hispanic children (RR=1.30, 95% CI: 0.76–2.25), but absolute numbers of ED visits in the latter group were small. Effect estimates for all-cause and respiratory ED visits were generally consistent with those from the ten-cities analysis. Table 2-11 presents results from a sub-analysis evaluating the effect of the ‘statewide’ p95 heat waves on pediatric ED visits among residents of the original ten cities. As shown, rate ratios from this sub-analysis were similar to, although less precise than, those from the statewide analysis.

For heat illness (Table 2-9), the statewide analysis provided more power than the ten-cities analysis, although numbers of ED visits in reference periods were still small and are not presented. Findings were consistent with those from the ten-cities analysis and showed an increased rate of ED visits for heat illness during heat waves, although estimates were still imprecise.

Sensitivity Analyses

Using secondary diagnostic fields in the ten-cities analysis, an additional 525 and 324 asthma/wheeze ED visits were identified during P95 and T90 heat wave days, respectively, and 533 and 326 during the corresponding reference days. The effect estimates decreased slightly when considering asthma/wheeze in any diagnostic field, but the conclusions did not change (RR_{T90} = 1.01 vs. 1.04, RR_{P95} = 1.00 vs. 1.02). For heat illness, 14 additional ED visits during P95 and four during T90 heat wave days were identified by examining secondary diagnostic fields, and two and zero during the corresponding reference days. The conclusions for heat illness also did not change by considering secondary diagnostic fields.

Discussion

This study identified heat waves, using two different definitions, in Massachusetts from 2005–2014 and quantified the short-term impact on pediatric emergency department visits for asthma/wheeze and other select diagnoses. Interestingly, for asthma/wheeze, the ten-cities analysis did not find an increased rate on heat wave compared to reference days, but the statewide analysis did, although excess numbers of visits were not very large. Across heat wave definitions and strata, findings from both the ten-cities and statewide analyses suggested a slightly increased rate of all-cause ED visits and little to no change in the rate for overall respiratory disease. The relative effects on ED visits for all diagnoses were small, but indicated hundreds of excess ED visits among children during heat waves in Massachusetts, and even thousands when lag days were considered.

In terms of heat illness, as expected, findings showed an elevated rate during heat waves and a sustained effect in the days following.

Previous studies examining the impact of heat waves on pediatric morbidity have varied in terms of population characteristics, geographic location, heat wave definitions, and health outcome measures. While these differences make it difficult to directly compare point estimates with those from the current study, there is general consistency in the findings (Leonardi et al. 2006; Knowlton et al. 2009; Nitschke et al. 2011). For instance, during a 2006 statewide heat wave in California, Knowlton et al. (2009) found that children aged 0–4 years had increased rates of ED visits for all causes (RR=1.05, 95% CI: 1.04–1.07) and heat illness (RR=6.17, 95% CI: 2.58–17.88), but not for respiratory illness. The authors did not look at asthma/wheeze separately, nor did they separate out children aged 5–17 from adults. In Adelaide, Australia, Nitschke et al. (2011) found no heat wave-associated increases in ED visit rates for all causes or respiratory disease among children aged 0–4 or 5–14 years, but did find elevated rates for heat illness during a particularly long and intense heat wave. They did not examine asthma/wheeze separately.

In terms of asthma/wheeze, findings from the ten-cities analysis of P95 heat waves suggested little to no effect, whereas those from the statewide analysis indicated an increased ED visit rate during heat waves compared to reference days. The discrepancy in relative findings between the two analyses might indicate that heat waves meeting the P95 definition are not all equivalent in how they impact health. The statewide findings may reflect that the P95 heat waves included in this analysis were more severe on average than those included in the ten-cities analysis (Appendix 2B and 2C). The nine heat waves affected all ten cities, and the assumption is the entire state, and the mean and median values of maximum HI were somewhat higher than for heat waves included in the ten-cities analysis (Table 2-5). Also, when the analysis of the effect of these nine 'statewide' heat waves was limited to ED visits in the original ten cities, the point estimates were consistent with those from the statewide analysis, especially considering the lag days, further suggesting that these heat waves had more of an impact (Table 2-11). Previous studies have also reported differences in pediatric ED visit rates by heat wave characteristics. Xu et al. (2014) reported an increase in pediatric ED visits for chronic lower respiratory disease (most of which was asthma) during heat waves lasting three or more days but not for those lasting two or more days. Xiao et al. (2017) found that rates of all-cause ED visits among children aged 0–14 years in Western Australia were higher on severe/extreme heat wave days and lower on low intensity heat wave days compared to on non-heat wave days. Although beyond the scope of the current study, a more nuanced examination of how heat wave intensity and duration influence pediatric ED visits in Massachusetts would be useful. In addition to heat wave characteristics, potential important mediators and/or modifiers, such as air pollution and access to air conditioning should be evaluated to better inform prevention efforts.

Stratified results from the statewide analysis for asthma/wheeze indicated potential effect measure modification (Table 2-10a). Although males had higher numbers of ED visits during both exposed and reference periods, females seemed to be more impacted by heat waves with greater absolute and relative effects. This was inconsistent with what was expected as prior studies have shown male children to be more vulnerable to heat-related health effects, including asthma (Xu et al. 2013; Xu et al. 2014; Winquist et al. 2016; O'Lenick et al. 2017). By race/ethnicity, we did not observe a greater impact on non-White children, as was hypothesized based on previous research. A recent study in Atlanta, Georgia reported stronger effects of heat on asthma ED visits among non-White, especially African American, children, compared to White children (O'Lenick et al. 2017). Also, there is a growing body of evidence demonstrating that disproportionate exposure to environmental hazards contributes to the racial/ethnic inequities in asthma (Levy et al. 2018). There were no noteworthy differences in rate ratios for asthma/wheeze by pediatric age group. Prior findings on the effect of heat on child morbidity by age group have been inconsistent (Kovats et al. 2004; Knowlton et al. 2009; Xu et al. 2013; Winquist et al. 2016; O'Lenick et al. 2017; Zhang et al. 2019). Recent U.S. (Winquist et al. 2016; O'Lenick et al. 2017) and Chinese (Zhang et al. 2019) studies reported greater effects of heat on asthma/wheeze ED visits and respiratory outpatient visits, respectively, among school-aged compared to younger children. Other studies found that children aged 0–4 years were particularly vulnerable to heat-related health outcomes overall (Kovats et al. 2004; Knowlton et al. 2009) and for asthma (Xu et al. 2013).

Sensitivity analyses were conducted to evaluate how solely using primary diagnosis to identify outcomes of interest may have affected results. Prior researchers have recommended assessing secondary as well as primary diagnostic fields in studies of heat-related hospital visits as findings may differ (Semenza et al. 1999; Knowlton et al. 2009; Winquist et al. 2016). For instance, Winquist et al. (2016) found striking differences in the association between heat and ED visits for cardiovascular outcomes when they considered all diagnostic fields versus the primary only. By limiting the current study to primary diagnosis, positive predictive value was enhanced in that there is high confidence that the ‘cases’ counted were true cases. However, in doing so, true cases that had asthma/wheeze or heat illness coded in a secondary diagnostic field may have been missed and the corresponding effects underestimated. Results of the sensitivity analyses including secondary diagnostic fields for asthma/wheeze and heat illness did not differ substantially from those including primary diagnosis only and the conclusions did not change.

Strengths of this study include use of three data sets to capture all ED visits, including those for potentially more serious incidents that resulted in an outpatient observation stay or inpatient hospitalization. Next, a large study sample size enabled evaluation of the effect by potential modifiers, although excess numbers tended to be small across strata for some outcomes. In addition, restricting reference periods to within a short time of the exposure period (i.e., within weeks in the same year) limited the influence of long-term time trends and seasonality. Lastly, this study examined the effect using two definitions of heat wave, one based on absolute and one on relative temperature measures.

This study had several limitations. There was potential for misclassification of exposure due to the city-level assignment of temperature or heat index and/or error in the actual measurements. We would expect such misclassification to be nondifferential. Also, while all ‘lag days’ in the ten-cities analysis were unexposed, this was not the case in the statewide analysis. In the statewide analysis (Tables 2-10a–c), some ‘lag days’ actually met HI criteria for a heat wave day for certain cities, and were thus misclassified as unexposed. As such, the effect estimates from analyses including these as lag days may not reflect residual effects of the defined heat waves, but might actually be due to the high HI on the lag days themselves. This was more common among heat wave lag days than reference lag days. This was especially true for the lag day 1 results, as these were most frequently misclassified. The list of cities and dates of ‘lag days’ that were actually exposed is included in Appendix 2D.

Also in terms of exposure, although two definitions of heat wave exposure were evaluated, it is possible that using alternative definitions of heat wave may have produced different results. Chen et al. (2017) in their study in Atlanta, Georgia reported differences in associations between heat wave and cause-specific ED visits depending on the temperature metric used, with maximum or minimum daily temperature-based heat waves more likely to show an effect than those based on mean temperature. Tong et al. (2010) found variation in the observed effect of heat wave on various indicators of morbidity across the ten different heat wave definitions used in Brisbane, Australia. They concluded that definitions need to be evaluated at the local level to determine which are most appropriate for assessing heat-related health impacts in a given area. Importantly, two recent studies in New England communities outside Massachusetts reported increased rates of all-cause ED visits (pediatric and all ages) associated with lower temperature and heat index levels than those evaluated in the current study (Kingsley et al. 2016; Wellenius et al. 2017). Additional research is needed to examine the effect of less extreme heat waves on pediatric ED visits in Massachusetts.

It is also possible that measures of heat exposure other than heat wave may show different results in this population. Prior research (Winquist et al. 2016; O'Lenick et al. 2017) in the Atlanta, Georgia area using continuous daily maximum temperature as the exposure measure (rather than heat wave) found associations with pediatric asthma morbidity. A recent study in the Netherlands found increases in respiratory emergency room admissions among 0–14 year-olds associated with both single days of high maximum temperatures and multiple consecutive days of moderately high temperatures (van Loenhout et al. 2018). In Greater London, UK, although there was no heat wave-associated increase in emergency hospital admissions for young children aged 0–4 years, researchers did find a slight increase in admissions with rise in mean daily temperature (Kovats et al. 2004). Kingsley et al. (2016) in Rhode Island found increased rates of all-cause pediatric ED visits with ten-degree increases in maximum daily temperature, especially with more moderate temperatures (e.g., 70–80°F). Use of alternative exposure metrics, such as daily maximum or mean temperature, should be considered in future studies of heat-related morbidity among Massachusetts children (Davis et al. 2016).

Next, an outcome measure distinct from ED visits may reveal a different impact of heat waves on pediatric respiratory morbidity (Leonardi et al. 2006; Nitschke et al. 2011; Zhang et al. 2019). For instance, while Nitschke et al. (2011) found no heat-wave associated increases in respiratory ED visits or hospitalizations among 5–14 year-olds in Brisbane, Australia, they did report an increased rate of respiratory ambulance call-outs in this age group. Similarly, a recent study in Cangnan, China found increases in outpatient visits for respiratory disease among children aged 4–17 years associated with heat waves during 2010–2012 (Zhang et al. 2019). Use of alternative outcome measures should be explored in future studies.

Lastly, effect modification by certain factors may have been masked or was not possible to assess. First, while excluding July 4th may have reduced potential for exposure misclassification and made the index and reference groups more comparable in terms of individual behaviors or other modifiers that may change on the holiday, it limits generalizability of the findings. Next, while the current study did stratify by two age groups of children in order to examine the effects among school-aged children and younger children separately, it is possible that an effect in a smaller age group was missed (Xu et al. 2014; Fuhrmann et al. 2016). Additionally, common measures of socioeconomic status (SES), a potential effect modifier, were not available for analysis. However, while the ED visit data did not contain information on income and education, use of source of payment in future research might provide some insight into SES (O’Lenick et al. 2017). Likewise, information on air conditioning use or activities prior to the visit, potential mediators or effect modifiers, was not available (Ostro et al. 2010). Finally, the current study did not include measures of air pollution, which was conceptually considered a causal intermediate in the pathway between heat and the health outcome examined (Reid et al. 2012; Buckley et al. 2014). Therefore, the observed effect estimates represent the total effect of heat wave on the selected health outcomes. Although beyond the scope of this study, future research to elucidate the direct and indirect short-term effects of temperature on morbidity in relation to, for instance, ozone, might better inform specific policies and interventions.

In summary, this study provided some evidence of increased rates of ED visits for asthma/wheeze among Massachusetts children during and immediately following heat waves, although excess numbers were small. Findings for overall respiratory disease did not suggest similar increases, underscoring the importance of analyzing asthma separately. Small relative increases in pediatric ED visits for all diagnoses during heat waves corresponded to hundreds of excess visits, especially when lag days were considered. Lastly, we found large relative increases in rates of visits for heat illness during heat waves, as expected, but estimates were imprecise due to small numbers of visits particularly on non-heat wave reference days.

Table 2-1. Diagnoses included with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9) codes and corresponding descriptions[1]

Term	ICD-9 Code	Description
Asthma/wheeze[2]	493	Asthma
	786.07	Wheezing
Respiratory disease[2]	460	Acute nasopharyngitis [common cold]
	461	Acute sinusitis
	462	Acute pharyngitis
	463	Acute tonsillitis
	464	Acute laryngitis and tracheitis
	465	Acute upper respiratory infections of multiple or unspecified sites
	466	Acute bronchitis and bronchiolitis
	477	Allergic rhinitis
	480	Viral pneumonia
	481	Pneumococcal pneumonia [*Streptococcus pneumoniae*]
	482	Other bacterial pneumonia
	483	Pneumonia due to other specified organism
	484	Pneumonia in infectious diseases classified elsewhere
	485	Bronchopneumonia, organism unspecified
	486	Pneumonia, organism unspecified
	491	Chronic bronchitis
	492	Emphysema
	493	Asthma
	496	Chronic airway obstruction, not elsewhere classified
	786.07	Wheezing
Heat illness[3]	992.0	Heat stroke and sunstroke
	992.1	Heat syncope
	992.2	Heat cramps
	992.3	Heat exhaustion, anhydrotic
	992.4	Heat exhaustion due to salt depletion
	992.5	Heat exhaustion, unspecified
	992.6	Heat fatigue, transient
	992.7	Heat edema
	992.8	Other specified heat effects
	992.9	Unspecified effects of heat and light

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[1] U.S. Department of Health and Human Services. Generic ICD-9-CM. Channel Publishing 2007.

[2] O'Lenick et al, 2017. [3] Winquist et al, 2016

Table 2-2. Characteristics of emergency department (ED) visits among children aged 0–17 years residing in the ten study cities by diagnosis, May–September 2005–2014

	All diagnoses		Respiratory disease		Asthma / wheeze		Heat illness	
	#	%	#	%	#	%	#	%
Total	644108	100.0	79824	100.0	22027	100.0	161	100.0
Month								
May	143615	22.3	21666	27.1	6413	29.1	11	6.8
June	128733	20.0	15427	19.3	3695	16.8	39	24.2
July	124217	19.3	11036	13.8	2210	10.0	70	43.5
August	119349	18.5	11565	14.5	2857	13.0	29	18.0
September	128194	19.9	20130	25.2	6852	31.1	12	7.5
Year								
2005	59912	9.3	7119	8.9	2056	9.3	18	11.2
2006	63215	9.8	7801	9.8	2352	10.7	…	
2007	61222	9.5	7088	8.9	2121	9.6	14	8.7
2008	63579	9.9	7952	10.0	2634	12.0	16	9.9
2009	72399	11.2	10404	13.0	2149	9.8	…	
2010	63945	9.9	7984	10.0	2106	9.6	20	12.4
2011	63552	9.9	7570	9.5	1931	8.8	15	9.3
2012	63885	9.9	7436	9.3	1871	8.5	19	11.8
2013	65169	10.1	7409	9.3	2132	9.7	20	12.4
2014	67230	10.4	9061	11.4	2675	12.1	17	10.6
City								
Boston	202471	31.4	26598	33.3	8585	39.0	45	28.0
Brockton	46960	7.3	5343	6.7	1448	6.6	23	14.3
Cambridge	17038	2.7	1787	2.2	533	2.4	…	
Lawrence	59583	9.3	8933	11.2	1593	7.2	…	
Lowell	45913	7.1	5711	7.2	1041	4.7	17	10.6
Lynn	40501	6.3	4898	6.1	1223	5.6	11	6.8
New Bedford	45144	7.0	4376	5.5	872	4.0	…	
Quincy	20937	3.3	2063	2.6	452	2.1	…	
Springfield	88094	13.7	10605	13.3	3461	15.7	21	13.0
Worcester	77467	12.0	9510	11.9	2819	12.8	19	11.8
ED Visit Disposition								
ED Discharge	625652	97.1	75398	94.5	19525	88.6	153	95.0
Inpatient Hospitalization	12805	2.0	3234	4.1	1894	8.6	…	
Outpatient Observation Stay	5651	0.9	1192	1.5	608	2.8	…	

Table 2-2 (cont.).

	All diagnoses		Respiratory disease		Asthma / wheeze		Heat illness	
	#	%	#	%	#	%	#	%
Age group (years)								
0–4	284269	44.1	44761	56.1	9998	45.4	26	16.2
5–17	359839	55.9	35063	43.9	12029	54.6	135	83.9
Sex								
Male	345215	53.6	44013	55.1	13518	61.4	90	55.9
Race/Ethnicity								
Hispanic	233376	36.2	31838	39.9	8143	37.0	34	21.1
White, non-Hispanic	173433	26.9	16771	21.0	3816	17.3	64	39.8
Black, non-Hispanic	153109	23.8	21074	26.4	7601	34.5	50	31.1
Other, non-Hispanic	62811	9.8	7667	9.6	1952	8.9	…	
Missing	21379	3.3	2474	3.1	515	2.3	…	

Note: Cells with n<11 are suppressed

Table 2-3. Select ambient temperature and heat index (HI) metrics by city, Massachusetts, May–September 2005–2014.

	Maximum daily temperature (°F):			Maximum daily HI (°F):			Thresholds based on 95th percentile of warm season HI values for a given city. (°F)	Number of days		Number of heat waves by definition	
City	Average	Range		Average	Range			Maximum temperature ≥ 90 °F	Maximum HI > 95th percentile	T90[1]	P95[2]
Boston	76.6	47.3	99.5	80.4	47.3	137.4	105.9	80	75	10	21
Brockton	76.9	46.4	97.7	80.6	46.4	131.3	111.3	76	73	13	21
Cambridge	76.8	47.3	98.6	80.6	47.3	132.8	112.9	85	75	11	20
Lawrence	77.0	48.2	97.7	80.5	48.2	132.6	111.0	82	75	10	23
Lowell	77.4	47.3	98.6	81.2	47.3	130.4	105.6	100	76	11	21
Lynn	75.9	47.3	98.6	79.4	47.3	132.8	104.0	57	76	7	24
New Bedford	76.1	47.3	97.7	79.4	47.3	130.3	106.7	36	76	5	20
Quincy	76.6	47.3	98.6	80.4	47.3	132.8	105.7	78	76	11	24
Springfield	78.1	49.1	99.5	81.9	49.1	130.5	111.0	89	75	14	21
Worcester	74.6	45.5	95.0	76.9	45.5	118.2	103.8	23	74	2	18

[1] T90 heat wave: ≥3 consecutive days with maximum ambient temperature ≥ 90 °F

[2] P95 heat wave: ≥2 consecutive days with maximum heat index > 95th percentile of warm season heat index

Table 2-4. Number of heat waves[1,2] by city and year, Massachusetts, 2005–2014.

City	All years		2005		2006		2007		2008		2009		2010		2011		2012		2013[3]		2014	
	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95	T90	P95
Boston	10	21	0	2	1	2	2	2	1	1	1	1	2	4	1	1	0	3	2	4	0	1
Brockton	13	21	0	3	1	2	2	2	2	2	1	1	2	4	1	1	2	3	2	3	0	0
Cambridge	11	20	0	3	1	2	2	2	1	1	1	1	2	3	1	1	1	3	2	3	0	1
Lawrence	10	23	0	3	0	3	2	3	1	1	1	1	2	3	1	1	1	3	2	4	0	1
Lowell	11	21	1	2	0	2	1	3	1	1	1	1	2	3	1	1	2	3	2	4	0	1
Lynn	7	24	0	2	1	3	1	3	0	2	1	1	2	4	1	1	0	2	1	4	0	2
New Bedford	5	20	0	2	1	3	0	1	1	2	0	1	2	4	0	1	0	3	1	3	0	0
Quincy	11	24	0	3	1	2	2	2	2	2	1	1	2	5	1	1	0	3	2	4	0	1
Springfield	14	21	2	3	2	2	0	3	2	2	1	1	2	3	1	1	2	3	2	3	0	0
Worcester	2	18	0	3	0	2	0	1	1	2	0	1	0	2	0	1	0	3	1	2	0	1

[1] T90 heat wave: ≥3 consecutive days with maximum ambient temperature ≥ 90 ºF

[2] P95 heat wave: ≥2 consecutive days with maximum heat index > 95th percentile of warm season heat index

[3] In 2013, for each city, one P95 heat wave was excluded from analysis due to lack of appropriate reference period.

Table 2-5. Maximum daily temperature (Tmax) and heat index (HImax) measures for heat waves[1,2] and reference days for ten-cities[3] and statewide analyses.

	Ten cities analysis								Statewide analysis			
	T90 Heat wave		Reference		P95 Heat wave		Reference		P95 Heat wave		Reference	
Measure	Tmax (°F)	HImax (°F)	Tmax (°F)	HImax (°F)	Tmax (°F)	HImax (°F)	Tmax (°F)	HImax (°F)	Tmax (°F)	HImax (°F)	Tmax (°F)	HImax (°F)
Average	93.0	112.9	81.0	85.7	92.2	111.5	80.4	84.8	93.6	115.7	80.0	83.7
Median	92.3	111.8	81.5	86.6	92.3	110.0	81.5	85.3	94.1	114.7	81.5	85.3
Mode	92.3	110.8	82.4	86.8	92.3	107.9	80.6	86.8	94.1	115.0	82.4	85.3
Minimum	90.5	100.0	54.5	54.5	86.0	97.6	53.6	53.6	86.9	98.4	64.4	64.9
Maximum	99.5	137.4	89.6	103.8	99.5	137.4	90.5	105.8	99.5	137.4	86.9	99.1

[1] T90 heat wave: ≥3 consecutive days with maximum ambient temperature ≥ 90 °F

[2] P95 heat wave: ≥2 consecutive days with maximum heat index > 95th percentile of warm season heat index

[3] Boston, Brockton, Cambridge, Lawrence, Lowell, Lynn, New Bedford, Quincy, Springfield, Worcester

Table 2-6a. Association between heat wave (T90 definition) and pediatric emergency department (ED) visits for *asthma/wheeze*, ten-cities analysis.

			Number of ED visits					
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio	95% Confidence Interval	
Overall		0	276	287	11	1.04	0.88	1.23
		1	369	377	8	1.02	0.89	1.18
		2	460	467	7	1.02	0.89	1.15
		3	550	549	-1	1.00	0.89	1.12
Age Group (years)	0–4	0	138	140	2	1.01	0.80	1.28
		1	174	183	9	1.05	0.85	1.29
		2	223	232	9	1.04	0.87	1.25
		3	268	275	7	1.03	0.87	1.21
	5–17	0	138	147	9	1.07	0.84	1.34
		1	195	194	-1	0.99	0.82	1.21
		2	237	235	-2	0.99	0.83	1.19
		3	282	274	-8	0.97	0.82	1.15
Sex	Male	0	178	175	-3	0.98	0.80	1.21
		1	234	226	-8	0.97	0.80	1.16
		2	286	274	-12	0.96	0.81	1.13
		3	345	324	-21	0.94	0.81	1.09
	Female	0	98	112	14	1.14	0.87	1.50
		1	135	151	16	1.12	0.89	1.41
		2	174	193	19	1.11	0.90	1.36
		3	205	225	20	1.10	0.91	1.33
Race/ Ethnicity	Hispanic	0	100	112	12	1.12	0.86	1.47
		1	144	154	10	1.07	0.85	1.34
		2	176	193	17	1.10	0.89	1.35
		3	202	216	14	1.07	0.88	1.30
	White non-Hispanic	0	42	50	8	1.19	0.79	1.79
		1	53	59	6	1.11	0.77	1.61
		2	66	71	5	1.08	0.77	1.50
		3	81	88	7	1.09	0.80	1.47
	Black non-Hispanic	0	109	104	-5	0.95	0.73	1.25
		1	145	137	-8	0.94	0.75	1.19
		2	185	171	-14	0.92	0.75	1.14
		3	223	201	-22	0.90	0.74	1.09
	Other non-Hispanic	0	21	14	-7	0.67	0.34	1.31
		1	22	17	-5	0.77	0.41	1.46
		2	26	20	-6	0.77	0.43	1.38
		3	35	29	-6	0.83	0.51	1.36

Table 2-6b. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *asthma/wheeze*, ten-cities analysis.

			Number of ED visits				95% Confidence Interval	
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio		
Overall		0	448	455	7	1.02	0.89	1.16
		1	633	656	23	1.04	0.93	1.16
		2	797	830	33	1.04	0.94	1.15
		3	1043	1000	-43	0.96	0.88	1.05
Age Group (years)	0–4	0	222	222	0	1.00	0.83	1.20
		1	307	319	12	1.04	0.89	1.22
		2	385	410	25	1.06	0.93	1.22
		3	489	491	2	1.00	0.89	1.14
	5–17	0	226	233	7	1.03	0.86	1.24
		1	326	337	11	1.03	0.89	1.20
		2	412	420	8	1.02	0.89	1.17
		3	554	509	-45	0.92	0.81	1.04
Sex	Male	0	289	288	-1	1.00	0.85	1.17
		1	409	404	-5	0.99	0.86	1.13
		2	513	513	0	1.00	0.88	1.13
		3	657	608	-49	0.93	0.83	1.03
	Female	0	159	167	8	1.05	0.85	1.31
		1	224	252	28	1.13	0.94	1.35
		2	284	317	33	1.12	0.95	1.31
		3	386	392	6	1.02	0.88	1.17
Race/ Ethnicity	Hispanic	0	168	162	-6	0.96	0.78	1.20
		1	244	249	5	1.02	0.86	1.22
		2	306	334	28	1.09	0.93	1.27
		3	392	396	4	1.01	0.88	1.16
	White non-Hispanic	0	83	97	14	1.17	0.87	1.57
		1	115	124	9	1.08	0.84	1.39
		2	142	146	4	1.03	0.82	1.30
		3	180	174	-6	0.97	0.78	1.19
	Black non-Hispanic	0	154	154	0	1.00	0.80	1.25
		1	217	218	1	1.00	0.83	1.21
		2	280	275	-5	0.98	0.83	1.16
		3	373	330	-43	0.88	0.76	1.03
	Other non-Hispanic	0	38	33	-5	0.87	0.54	1.38
		1	49	46	-3	0.94	0.63	1.40
		2	59	53	-6	0.90	0.62	1.30
		3	77	71	-6	0.92	0.67	1.27

Table 2-7a. Association between heat wave (T90 definition) and pediatric emergency department (ED) visits for *respiratory disease*, ten-cities analysis.

			Number of ED visits				95% Confidence Interval	
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio		
Overall		0	1256	1245	-11	0.99	0.92	1.07
		1	1616	1633	17	1.01	0.94	1.08
		2	2002	2016	14	1.01	0.95	1.07
		3	2336	2371	35	1.02	0.96	1.07
Age Group (years)	0–4	0	740	747	7	1.01	0.91	1.12
		1	937	967	30	1.03	0.94	1.13
		2	1183	1206	23	1.02	0.94	1.10
		3	1386	1421	35	1.03	0.95	1.10
	5–17	0	516	498	-18	0.97	0.85	1.09
		1	679	666	-13	0.98	0.88	1.09
		2	819	810	-9	0.99	0.90	1.09
		3	950	950	0	1.00	0.91	1.09
Sex	Male	0	695	672	-23	0.97	0.87	1.08
		1	876	870	-6	0.99	0.90	1.09
		2	1081	1068	-13	0.99	0.91	1.08
		3	1274	1255	-19	0.99	0.91	1.06
	Female	0	561	573	12	1.02	0.91	1.15
		1	740	763	23	1.03	0.93	1.14
		2	921	948	27	1.03	0.94	1.13
		3	1062	1116	54	1.05	0.97	1.14
Race/ Ethnicity	Hispanic	0	597	532	-65	0.89	0.79	1.00
		1	732	716	-16	0.98	0.88	1.08
		2	888	884	-4	1.00	0.91	1.09
		3	1024	1022	-2	1.00	0.92	1.09
	White non-Hispanic	0	223	248	25	1.11	0.93	1.33
		1	302	329	27	1.09	0.93	1.27
		2	373	394	21	1.06	0.92	1.22
		3	420	473	53	1.13	0.99	1.28
	Black non-Hispanic	0	313	334	21	1.07	0.91	1.25
		1	427	424	-3	0.99	0.87	1.14
		2	539	531	-8	0.99	0.87	1.11
		3	641	627	-14	0.98	0.88	1.09
	Other non-Hispanic	0	89	95	6	1.07	0.80	1.43
		1	111	116	5	1.05	0.81	1.36
		2	143	148	5	1.04	0.82	1.30
		3	176	178	2	1.01	0.82	1.25

Table 2-7b. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *respiratory disease*, ten-cities analysis.

		Lag day	Number of ED visits			Rate Ratio	95% Confidence Interval	
			Reference days	Heat wave days	Excess			
Overall		0	2051	1973	-78	0.96	0.90	1.02
		1	2812	2769	-43	0.98	0.93	1.04
		2	3542	3536	-6	1.00	0.95	1.05
		3	4568	4304	-264	0.94	0.90	0.98
Age Group (years)	0–4	0	1219	1168	-51	0.96	0.88	1.04
		1	1641	1610	-31	0.98	0.92	1.05
		2	2086	2076	-10	1.00	0.94	1.06
		3	2700	2529	-171	0.94	0.89	0.99
	5–17	0	832	805	-27	0.97	0.88	1.07
		1	1171	1159	-12	0.99	0.91	1.07
		2	1456	1460	4	1.00	0.93	1.08
		3	1868	1775	-93	0.95	0.89	1.01
Sex	Male	0	1144	1077	-67	0.94	0.87	1.02
		1	1553	1496	-57	0.96	0.90	1.03
		2	1956	1901	-55	0.97	0.91	1.04
		3	2499	2308	-191	0.92	0.87	0.98
	Female	0	907	896	-11	0.99	0.90	1.08
		1	1259	1272	13	1.01	0.93	1.09
		2	1586	1634	48	1.03	0.96	1.10
		3	2069	1995	-74	0.96	0.91	1.03
Race/ Ethnicity	Hispanic	0	887	810	-77	0.91	0.83	1.00
		1	1203	1171	-32	0.97	0.90	1.06
		2	1482	1504	22	1.01	0.94	1.09
		3	1880	1823	-57	0.97	0.91	1.03
	White non-Hispanic	0	427	447	20	1.05	0.92	1.20
		1	583	602	19	1.03	0.92	1.16
		2	748	746	-2	1.00	0.90	1.10
		3	933	914	-19	0.98	0.89	1.07
	Black non-Hispanic	0	504	493	-11	0.98	0.86	1.11
		1	696	685	-11	0.98	0.89	1.09
		2	886	879	-7	0.99	0.90	1.09
		3	1187	1060	-127	0.89	0.82	0.97
	Other non-Hispanic	0	175	165	-10	0.94	0.76	1.17
		1	239	221	-18	0.92	0.77	1.11
		2	309	294	-15	0.95	0.81	1.12
		3	410	365	-45	0.89	0.77	1.03

Table 2-8a. Association between heat wave (T90 definition) and pediatric emergency department (ED) visits for *all diagnoses*, ten-cities analysis.

			Number of ED visits					
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio	95% Confidence Interval	
Overall		0	13486	13774	288	1.02	1.00	1.05
		1	17187	17747	560	1.03	1.01	1.05
		2	20792	21663	871	1.04	1.02	1.06
		3	24258	25439	1181	1.05	1.03	1.07
Age Group (years)	0–4	0	6052	6214	162	1.03	0.99	1.06
		1	7678	8030	352	1.05	1.01	1.08
		2	9333	9821	488	1.05	1.02	1.08
		3	10968	11520	552	1.05	1.02	1.08
	5–17	0	7434	7560	126	1.02	0.98	1.05
		1	9509	9717	208	1.02	0.99	1.05
		2	11459	11842	383	1.03	1.01	1.06
		3	13290	13919	629	1.05	1.02	1.07
Sex	Male	0	7223	7392	169	1.02	0.99	1.06
		1	9214	9466	252	1.03	1.00	1.06
		2	11116	11563	447	1.04	1.01	1.07
		3	13003	13569	566	1.04	1.02	1.07
	Female	0	6263	6382	119	1.02	0.98	1.06
		1	7973	8281	308	1.04	1.01	1.07
		2	9676	10100	424	1.04	1.02	1.07
		3	11255	11870	615	1.05	1.03	1.08
Race/ Ethnicity	Hispanic	0	5498	5549	51	1.01	0.97	1.05
		1	6964	7115	151	1.02	0.99	1.06
		2	8336	8641	305	1.04	1.01	1.07
		3	9575	10077	502	1.05	1.02	1.08
	White non-Hispanic	0	3165	3295	130	1.04	0.99	1.09
		1	4059	4213	154	1.04	0.99	1.08
		2	4876	5171	295	1.06	1.02	1.10
		3	5757	6103	346	1.06	1.02	1.10
	Black non-Hispanic	0	3246	3281	35	1.01	0.96	1.06
		1	4151	4257	106	1.03	0.98	1.07
		2	5131	5207	76	1.01	0.98	1.05
		3	6036	6176	140	1.02	0.99	1.06
	Other non-Hispanic	0	1146	1202	56	1.05	0.97	1.14
		1	1458	1569	111	1.08	1.00	1.16
		2	1766	1911	145	1.08	1.01	1.15
		3	2097	2232	135	1.06	1.00	1.13

Table 2-8b. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *all diagnoses*, ten-cities analysis.

		Lag day	Number of ED visits			Rate Ratio	95% Confidence Interval	
			Reference days	Heat wave days	Excess			
Overall		0	21690	21920	230	1.01	0.99	1.03
		1	29343	30125	782	1.03	1.01	1.04
		2	36650	38134	1484	1.04	1.03	1.06
		3	46582	46252	-330	0.99	0.98	1.01
Age Group (years)	0–4	0	9755	9922	167	1.02	0.99	1.05
		1	13141	13609	468	1.04	1.01	1.06
		2	16473	17310	837	1.05	1.03	1.07
		3	21091	20992	-99	1.00	0.98	1.01
	5–17	0	11935	11998	63	1.01	0.98	1.03
		1	16202	16516	314	1.02	1.00	1.04
		2	20177	20824	647	1.03	1.01	1.05
		3	25491	25260	-231	0.99	0.97	1.01
Sex	Male	0	11621	11725	104	1.01	0.98	1.04
		1	15708	16025	317	1.02	1.00	1.04
		2	19641	20337	696	1.04	1.02	1.06
		3	24981	24654	-327	0.99	0.97	1.00
	Female	0	10068	10195	127	1.01	0.99	1.04
		1	13634	14099	465	1.03	1.01	1.06
		2	17008	17796	788	1.05	1.02	1.07
		3	21599	21597	-2	1.00	0.98	1.02
Race/ Ethnicity	Hispanic	0	8068	8141	73	1.01	0.98	1.04
		1	10914	11175	261	1.02	1.00	1.05
		2	13593	14182	589	1.04	1.02	1.07
		3	17053	17251	198	1.01	0.99	1.03
	White non-Hispanic	0	5939	5973	34	1.01	0.97	1.04
		1	7996	8167	171	1.02	0.99	1.05
		2	9950	10267	317	1.03	1.00	1.06
		3	12393	12409	16	1.00	0.98	1.03
	Black non-Hispanic	0	4871	4979	108	1.02	0.98	1.06
		1	6567	6877	310	1.05	1.01	1.08
		2	8235	8716	481	1.06	1.03	1.09
		3	11011	10602	-409	0.96	0.94	0.99
	Other non-Hispanic	0	2046	2081	35	1.02	0.96	1.08
		1	2802	2855	53	1.02	0.97	1.07
		2	3535	3595	60	1.02	0.97	1.07
		3	4452	4329	-123	0.97	0.93	1.01

Table 2-9. Rate ratios (RR) and 95% confidence intervals (CI) for the association between heat wave and pediatric emergency department (ED) visits for *heat illness* by heat wave definition, Massachusetts, 2005–2014

	Ten-cities[1] analysis								Statewide analysis			
	T90[2]				P95[3]				P95[3]			
Lag day	Excess number of ED visits	RR	95% CI		Excess number of ED visits	RR	95% CI		Excess number of ED visits	RR	95% CI	
0	36	19.00	4.58	78.76	48	13.00	4.70	35.94	93	11.33	5.73	22.41
1	35	12.67	3.91	41.03	47	8.83	3.80	20.55	97	7.93	4.55	13.82
2	36	10.00	3.58	27.95	46	6.11	3.02	12.36	100	6.26	3.86	10.16
3	34	5.25	2.46	11.18	42	3.80	2.15	6.71	100	5.17	3.34	8.00

[1] Boston, Brockton, Cambridge, Lawrence, Lowell, Lynn, New Bedford, Quincy, Springfield, Worcester

[2] T90 heat wave: ≥3 consecutive days with maximum ambient temperature ≥ 90 ºF

[3] P95 heat wave: ≥2 consecutive days with maximum heat index > 95th percentile of warm season heat index

Table 2-10a. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *asthma/wheeze*, statewide analysis.

			Number of ED visits				95% Confidence Interval	
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio		
Overall		0	375	429	54	1.14	1.00	1.31
		1	543	623	80	1.15	1.02	1.29
		2	714	809	95	1.13	1.02	1.25
		3	906	998	92	1.10	1.01	1.21
Age Group (years)	0–4	0	164	188	24	1.15	0.93	1.41
		1	240	269	29	1.12	0.94	1.33
		2	323	349	26	1.08	0.93	1.26
		3	403	436	33	1.08	0.94	1.24
	5–17	0	211	241	30	1.14	0.95	1.37
		1	303	354	51	1.17	1.00	1.36
		2	391	460	69	1.18	1.03	1.35
		3	503	562	59	1.12	0.99	1.26
Sex	Male	0	235	247	12	1.05	0.88	1.26
		1	343	358	15	1.04	0.90	1.21
		2	449	481	32	1.07	0.94	1.22
		3	565	593	28	1.05	0.94	1.18
	Female	0	140	182	42	1.30	1.04	1.62
		1	200	265	65	1.33	1.10	1.59
		2	265	328	63	1.24	1.05	1.46
		3	341	405	64	1.19	1.03	1.37
Race/ Ethnicity	Hispanic	0	93	94	1	1.01	0.76	1.35
		1	133	141	8	1.06	0.84	1.34
		2	179	197	18	1.10	0.90	1.35
		3	226	243	17	1.08	0.90	1.29
	White non-Hispanic	0	166	211	45	1.27	1.04	1.56
		1	231	291	60	1.26	1.06	1.50
		2	303	366	63	1.21	1.04	1.41
		3	387	436	49	1.13	0.98	1.29
	Black non-Hispanic	0	86	90	4	1.05	0.78	1.41
		1	129	134	5	1.04	0.82	1.32
		2	170	176	6	1.04	0.84	1.28
		3	208	219	11	1.05	0.87	1.27
	Other non-Hispanic	0	23	30	7	1.30	0.76	2.25
		1	37	44	7	1.19	0.77	1.84
		2	47	50	3	1.06	0.71	1.58
		3	67	72	5	1.07	0.77	1.50

Table 2-10b. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *respiratory disease*, statewide analysis.

			Number of ED visits				95% Confidence Interval	
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio		
Overall		0	1862	1896	34	1.02	0.96	1.09
		1	2749	2798	49	1.02	0.97	1.07
		2	3672	3794	122	1.03	0.99	1.08
		3	4598	4787	189	1.04	1.00	1.08
Age Group (years)	0–4	0	1008	1006	-2	1.00	0.91	1.09
		1	1464	1463	-1	1.00	0.93	1.07
		2	1974	1970	-4	1.00	0.94	1.06
		3	2482	2525	43	1.02	0.96	1.08
	5–17	0	854	890	36	1.04	0.95	1.14
		1	1285	1335	50	1.04	0.96	1.12
		2	1698	1824	126	1.07	1.01	1.15
		3	2116	2262	146	1.07	1.01	1.13
Sex	Male	0	1027	1018	-9	0.99	0.91	1.08
		1	1514	1489	-25	0.98	0.92	1.06
		2	2010	2036	26	1.01	0.95	1.08
		3	2512	2560	48	1.02	0.96	1.08
	Female	0	835	878	43	1.05	0.96	1.16
		1	1235	1309	74	1.06	0.98	1.15
		2	1662	1758	96	1.06	0.99	1.13
		3	2086	2227	141	1.07	1.01	1.13
Race/ Ethnicity	Hispanic	0	468	471	3	1.01	0.89	1.14
		1	691	712	21	1.03	0.93	1.14
		2	925	946	21	1.02	0.93	1.12
		3	1170	1197	27	1.02	0.94	1.11
	White non-Hispanic	0	934	946	12	1.01	0.93	1.11
		1	1361	1372	11	1.01	0.94	1.09
		2	1825	1892	67	1.04	0.97	1.11
		3	2268	2375	107	1.05	0.99	1.11
	Black non-Hispanic	0	282	276	-6	0.98	0.83	1.16
		1	416	412	-4	0.99	0.86	1.13
		2	543	551	8	1.01	0.90	1.14
		3	675	691	16	1.02	0.92	1.14
	Other non-Hispanic	0	139	158	19	1.14	0.91	1.43
		1	211	220	9	1.04	0.86	1.26
		2	279	293	14	1.05	0.89	1.24
		3	350	376	26	1.07	0.93	1.24

Table 2-10c. Association between heat wave (P95 definition) and pediatric emergency department (ED) visits for *all diagnoses*, statewide analysis.

			Number of ED visits				95% Confidence Interval	
		Lag day	Reference days	Heat wave days	Excess	Rate Ratio		
Overall		0	25142	25484	342	1.01	1.00	1.03
		1	36139	37338	1199	1.03	1.02	1.05
		2	47334	49385	2051	1.04	1.03	1.06
		3	58597	61447	2850	1.05	1.04	1.06
Age Group (years)	0–4	0	9427	9671	244	1.03	1.00	1.06
		1	13622	14188	566	1.04	1.02	1.07
		2	17920	18814	894	1.05	1.03	1.07
		3	22281	23478	1197	1.05	1.03	1.07
	5–17	0	15715	15813	98	1.01	0.98	1.03
		1	22517	23150	633	1.03	1.01	1.05
		2	29414	30571	1157	1.04	1.02	1.06
		3	36316	37969	1653	1.05	1.03	1.06
Sex	Male	0	13710	13819	109	1.01	0.98	1.03
		1	19695	20153	458	1.02	1.00	1.04
		2	25825	26725	900	1.03	1.02	1.05
		3	31811	33260	1449	1.05	1.03	1.06
	Female	0	11432	11664	232	1.02	0.99	1.05
		1	16444	17184	740	1.05	1.02	1.07
		2	21509	22659	1150	1.05	1.03	1.07
		3	26786	28186	1400	1.05	1.03	1.07
Race/ Ethnicity	Hispanic	0	4859	5007	148	1.03	0.99	1.07
		1	6896	7313	417	1.06	1.03	1.10
		2	9053	9640	587	1.06	1.03	1.10
		3	11253	11917	664	1.06	1.03	1.09
	White non-Hispanic	0	14900	14871	-29	1.00	0.98	1.02
		1	21485	21847	362	1.02	1.00	1.04
		2	28240	28934	694	1.02	1.01	1.04
		3	34897	36117	1220	1.04	1.02	1.05
	Black non-Hispanic	0	2914	2984	70	1.02	0.97	1.08
		1	4151	4319	168	1.04	1.00	1.09
		2	5373	5683	310	1.06	1.02	1.10
		3	6673	7050	377	1.06	1.02	1.10
	Other non-Hispanic	0	1807	1880	73	1.04	0.98	1.11
		1	2646	2752	106	1.04	0.99	1.10
		2	3397	3654	257	1.08	1.03	1.13
		3	4194	4524	330	1.08	1.03	1.13

Table 2-11. Rate ratios (RR) and 95% confidence intervals (CI) for the association between 'statewide' heat waves[1] and pediatric emergency department (ED) visits, original ten cities[2] and all of Massachusetts 2005–2014.

		All Diagnoses								
		Ten cities						Massachusetts		
		Number of ED visits								
Outcome	Lag Day	Reference days	Heat wave days	Excess	RR	95% CI		RR	95% CI	
All diagnoses	0	8204	8368	164	1.02	0.99	1.05	1.01	1.00	1.03
	1	11724	12215	491	1.04	1.02	1.07	1.03	1.02	1.05
	2	15185	16096	911	1.06	1.04	1.08	1.04	1.03	1.06
	3	18869	19988	1119	1.06	1.04	1.08	1.05	1.04	1.06
Respiratory disease	0	709	719	10	1.01	0.91	1.13	1.02	0.96	1.09
	1	1063	1074	11	1.01	0.93	1.10	1.02	0.97	1.07
	2	1400	1439	39	1.03	0.95	1.11	1.03	0.99	1.08
	3	1766	1831	65	1.04	0.97	1.11	1.04	1.00	1.08
Asthma/ wheeze	0	167	182	15	1.09	0.88	1.34	1.14	1.00	1.31
	1	242	271	29	1.12	0.94	1.33	1.15	1.02	1.29
	2	309	350	41	1.13	0.97	1.32	1.13	1.02	1.25
	3	388	438	50	1.13	0.98	1.29	1.10	1.01	1.21

[1] ‘Statewide’ heat waves: P95 heat waves that were used in the statewide analysis

[2] Boston, Brockton, Cambridge, Lawrence, Lowell, Lynn, New Bedford, Quincy, Springfield, Worcester

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STUDY 3: EVALUATING THE RELATIONSHIP BETWEEN SUMMER SEASON AND INFANT SALMONELLOSIS IN THE UNITED STATES

Introduction

Nontyphoidal *Salmonella* infection, or salmonellosis, is an important public health issue in the United States. Annually, an estimated 1.2 million illnesses, 23,000 hospitalizations and 450 deaths in the U.S. are due to *Salmonella*, and billions of dollars are attributed to *Salmonella* each year (Frenzen et al. 1999; Scallan et al. 2011). Healthy People 2020 includes reducing *Salmonella* infection as a national food safety objective (CDC 2014c). Most persons with salmonellosis develop a gastrointestinal illness characterized by diarrhea, fever and abdominal cramps between 12 and 72 hours after infection. While most healthy individuals recover on their own within a few days, invasive infections and severe illness resulting in hospitalization and death may occur, especially among older adults, persons with compromised immune systems and young children (Cohen 1991; Eng et al. 2015; CDC 2019a).

Infants (age <1 year) have an incidence rate of *Salmonella* infection approximately eight times that of the general population, and about one out of every four infected infants requires hospitalization (Jones et al. 2008; Cheng et al. 2013; CDC 2018). Risk factors for infant infection have not been fully elucidated (Cohen 1991; Rowe et al. 2004; Jones et al. 2006; Patrick et al. 2010). *Salmonella* serotypes have varying transmission pathways and frequencies according to age (Jones et al. 2006; Jones et al. 2008; Cheng et al. 2013; Crim et al. 2014; Judd et al. 2019). While an estimated 94% of all salmonellosis is foodborne, environmental sources (e.g., contact with reptiles; household member with diarrhea in prior four weeks) may be more important for infants

(Ackman et al. 1995; Schutze et al. 1999; Rowe et al. 2004; Jones et al. 2006; Patrick et al. 2010; Scallan et al. 2011). Additionally, host factors, such as an immature immune system, may make infants more susceptible to infection and severe illness (Cohen 1991).

Studies, both in the U.S. and abroad, have found that salmonellosis incidence varies by season and is positively associated with ambient temperature (D'Souza et al 2004; Kovats et al. 2004; Fleury et al. 2006; Naumova et al. 2007; Lake et al. 2009; Britton et al. 2010; Kendrovski et al. 2011; Lal et al. 2012; Akil et al. 2014; Jiang et al. 2015). This may be due to a combination of factors including the direct influence of temperature on bacterial growth (e.g., optimal between 95–98.6 ºF), as well as the indirect effect of temperature-related changes in human behavior (e.g., recreational activities, food choices, food preparation and storage) (Kovats et al. 2004; Akil et al. 2014). There is also some evidence that the association with temperature varies by *Salmonella* serotype (Kovats et al. 2004; Lake et al. 2009; Milazzo et al. 2016). There is potential for salmonellosis in infants, an already susceptible population, to be disproportionately affected by temperature increases due to climate change. Yet, while studies have assessed the overall association between season/temperature and salmonellosis, there is a lack examining the association by age and serotype simultaneously.

The aim of this study was to assess the relationship between temperature-based season and infant *Salmonella* infection in the U.S. using relative and absolute measures of comparison, and to explore how any detected association may differ from that among other age groups overall, by select demographic factors, and by serotype. We hypothesized that: 1) the incidence of infant salmonellosis will be higher in summer compared to winter; 2) the effect of season on incident infection among infants will be greater compared to the effect in other age groups and; 3) the increase in incidence among infants during the summer will vary by serotype and will be largest for serotypes that are most prevalent among infants.

Methods

Outcome and Exposure

Data on incident human *Salmonella* infections in the U.S. for the years 2010–2015 from the U.S. Centers for Disease Control and Prevention's Laboratory-based Enteric Disease Surveillance (LEDS) system were used for this study. State public health laboratories report isolates from laboratory-confirmed human *Salmonella* infections to LEDS. For each infection reported to LEDS, only the first isolate of a given serotype and specimen source (e.g., blood) within a 30-day period is included (CDC 2018).

The outcome was defined as laboratory-confirmed nontyphoidal *Salmonella* infection, excluding serotypes Typhi and Paratyphi (except Paratyphi B var. L(+) tartrate+) (CDC 2019b). For exposure, date of specimen collection was used to identify months and seasons. Season was defined using the meteorological definition of 3-month groupings based on temperature cycles for the northern hemisphere (Figure 1) (NOAA 2015). Summer (exposed), generally considered the hottest time of year, included June, July and August. Winter (unexposed), generally considered the coldest time of year, included December, January and February.

Covariables

For each infection, information on serotype, age, sex (male; female), race (American Indian/Alaska Native; Asian/Pacific Islander; Black/African American; White), ethnicity (Hispanic; non-Hispanic) and U.S. Census region and division of residence of infected person was evaluated. The four U.S. Census regions and nine divisions are available in Figure 2.

Population estimates

Corresponding population data from the U.S. Census was used for denominators of incidence rates (Szklo and Nieto 2012; US Census 2016a; US Census 2016b). See Appendix 3A for details.

Analytic Approach

Descriptive analyses were conducted to evaluate data completeness and to explore the distribution of infection by age group. Age was categorized into four groups: < 1 year (infants); 1–4 years; 5–17 years; and ≥18 years. Within age group, stratified analyses were carried out to further examine distribution by sex, race, ethnicity, census region and division, month and year of infection, and serotype. Incidence rates were calculated among select subgroups as the number of infections divided by the U.S. resident population for the specified time period and characteristic (e.g., age group), multiplied by 100,000. This is consistent with CDC’s method for calculating rates of nationally notifiable diseases (Crim et al. 2014). For incidence rates, we estimated 95% confidence intervals (Aschengrau and Seage 2008).

To determine the relationship between summer (vs. winter) and incident

Salmonella infection on relative and absolute scales, incidence rate ratios and incidence rate differences, respectively, were calculated. Corresponding 95% confidence intervals were estimated for each measure (Aschengrau and Seage 2008). These measures were calculated overall and within strata of age group, sex and geographic area to assess effect modification by these factors. Finally, rates due to interdependence were estimated to evaluate the joint effect on salmonellosis incidence of season and census region (Greenland et al. 2008). We used the following formula:

$R(I) = R(E+,C+) - [R(E-,C+) - R(E-,C-)] - [R(E+,C-) - R(E-,C-)] - R(E-,C-).$

Secondary Analyses

Age Subgroups of Infants:

Prior research has shown differences in salmonellosis by infant age (Cheng et al. 2013). To assess whether the association of interest in this study differed by infant age, analyses comparing incidence rates in summer compared to winter overall and by select factors were carried out among four age subgroups of infants: age < 3 months; 3–5 months; 6–8 months; 9–11 months.

Extended Exposure Period:

Previous studies have suggested that increases in reported salmonellosis may occur for up to 5 weeks after exposure to high environmental temperature (D'Souza et al. 2004; Kovats et al. 2004; Naumova et al. 2007; Lake et al. 2009). Thus, we also evaluated the potential impact of extending the exposure period one month through September, and corresponding reference period through March.

Results

Overall, there were 264,908 nontyphoidal *Salmonella* infections reported to LEDS from 2010 through 2015, for an average of 44,151 per year (Table 3-1a). Ten percent of infections were among children < 1 year old (infants), 14.8% among those aged 1–4 years, 14.7% among those aged 5–17 years, and 59.2% were among adults aged ≥18 years. Age was missing for 1.3% of infections and the percent of values missing for each of sex and geographic area of residence was less than 6.0% across age groups. Because values for race and ethnicity were missing for a large portion of infections (63.4% and 78.4%, respectively), these variables were not evaluated in any further analyses.

Table 3-1b shows the distribution of the thirty most common *Salmonella* serotypes within each age group. The top thirty comprised 86.5% of all infections with serotype information; serotype was unknown for 7.5% of infections. Among infants, Newport was the most common serotype (14.1%), followed by Typhimurium (10.3%), Javiana (7.8%), Enteritidis (5.0%), and Muenchen (4.0%). For the three older age groups, the top five serotypes were Enteritidis, Typhimurium, Newport, Javiana, and I 4,[5],12:i:, although the rank order varied slightly between the groups.

Incidence rates of nontyphoidal salmonellosis by age group and select characteristics are presented in Table 3-2. Incidence tended to decrease with increasing age. Infants had the highest rate with 111.95 infections per 100,000 population, followed by children aged 1–4 (40.66 per 100,000), those aged 5–17 years (12.06), and adults aged 18 and older (10.84). Across strata, infants consistently had the highest rates, followed by children aged 1–4 years. Males tended to have higher rates among children of all ages, but females had higher rates among adults. By census region, rates were highest in the South and corresponding divisions for infants and young children, whereas the differences were less remarkable in the other two age groups. The South region had by far the highest infant rate at 188.42 per 100,000 (95% CI: 185.60–191.24), with the rate in the West South Central division of 213.05 per 100,000 (95% CI: 208.03–218.07) exceeding those of the other two divisions in the region. By month, across age groups, the rate was highest in August and lowest in February (Figure 3-3a). Age group-specific rates were fairly stable across years of the study period (Figure 3-3b).

Figures 3-4a, 3-4b, 3-4c, and 3-4d present findings from analyses comparing summer and winter rates of nontyphoidal salmonellosis by age group and select additional factors. (See Appendix 3B for additional details). Overall, across age groups, the rate was higher in summer compared to winter with rate ratios ranging from 2.53 (95% CI: 2.43–2.62) among infants to 2.95 (95% CI: 2.86–3.05) among those 5–17 years old (Figure 3-4a). Whereas the rate ratios did not vary substantially across age groups, the rate differences per 100,000 population decreased with increasing age, but were all greater than zero (Figure 3-4b). Overall, there were 7.91 (95% CI: 7.60–8.23) excess cases per 100,000 in summer among infants, 3.29 (95% CI: 3.20–3.39) among young children aged 1–4 years, 1.04 (95% CI: 1.01–1.07) among those aged 5–17 years and 0.87 (95% CI: 0.85–0.88) among adults aged ≥18 years. There did not appear to be effect measure modification by sex on either a relative or absolute scale (Figures 3-4a and 3-4b).

Across census regions (Figures 3-4a and 3-4b) and divisions (Figures 3-4c and 3-4d), infants consistently had higher rate differences compared to other age groups, but not rate ratios. The South region and corresponding divisions had the highest rate ratios and rate differences for infants and young children, but not for the other two age groups. Overall, the rate difference was highest among infants in the South region, who experienced 15.02 (95% CI: 14.37–15.67) excess cases per 100,000 in the summer compared to winter, followed by infants in the Northeast with 6.15 (95% CI: 5.44–6.86) excess cases per 100,000.

To assess the joint effect of summer with census region on salmonellosis incidence, we calculated rates due to interdependence or R(I) (Table 3-3). A positive R(I) would indicate that there were more cases from the joint effect of two exposures than would be expected from either alone (Greenland et al. 2008). Results from the analysis of the joint effect of summer (vs. winter) and the South (vs. all other regions combined) by age group showed positive, decreasing R(I) across age groups. Among infants in the South in the summer, there were 11.27 per 100,000 more cases than would be expected from either living in the South or experiencing summer alone. This decreased to 3.41 among young children aged 1–4 years, 0.37 among children aged 5–17, and 0.22 among adults.

Results for specific *Salmonella* serotypes are presented in Tables 3-4a and 3-4b. (See Appendix 3C for additional details). Rates of infection for most serotypes increased during summer compared to winter across age groups. Among infants, relative increases in rates were greatest for serotypes Javiana, Newport, Bareilly, and Muenchen, with rate ratios of 5.47 (95% CI: 4.63 – 6.46), 4.98 (95% CI: 4.41–5.62), 4.13 (95% CI: 2.84 – 6.00), and 3.74 (95% CI: 3.05–4.59), respectively (Table 3-4a). These rate ratios were generally consistent across age groups. Infants had a greater rate difference for each of these four serotypes (Table 3-4b), although actual numbers of serotype Bareilly infections were small (Appendix 3C). For serotype Enteriditis, the rate ratio increased somewhat with age from 1.75 (95% CI: 1.48–2.05) among infants to 2.48 (95% CI: 2.40–2.56) among adults, but the rate differences were similar across age groups. For serotype Rubislaw, the number and rate of infections in summer were highest for infants, along with the rate ratio and rate difference (Appendix 3C).

Secondary Analyses

Age Subgroups of Infants:

Incidence rates of nontyphoidal salmonellosis by infant age group and select characteristics are presented in Table 3-5. Among infant infections, 23.4% were among those aged <3 months, 31.2% among those 3–5 months, 23.5% among those 6–8 months, and 21.8% among those 9–11 months. The average annual incidence rate was highest among infants aged 3–5 months (139.77 per 100,000), followed by those aged 6–8 months (105.34), <3 months (104.89) and 9–11 months (95.29). Males had higher rates than females in each infant age group. Across age groups, infants in the South region and corresponding divisions had the highest rates. By month, rates peaked in August and September and were lowest in February for all age groups (Figure 3-5a). Rates did not vary substantially by year across the study period within infant age groups (Figure 3-5b).

Across infant age groups, rates were consistently higher in summer than winter and there did not appear to be dramatic differences in relative or absolute measures of comparison (Figures 3-6a and 3-6b). Rate ratios ranged from 2.38 (95% CI: 2.22–2.55) among 3–5 month olds to 2.71 (95% CI: 2.49–2.94) among 9–11 month olds, and rate differences ranged from 7.26 (95% CI: 6.65–7.87) per 100,000 in 6–8 month olds to 9.32 (95% CI: 8.62–10.03) in 3–5 month olds. Findings from stratified analyses were generally consistent across infant age groups and with those for all infants described above. Overall, the rate difference was highest among infants aged 3–5 months in the South region, who experienced 18.27 (95% CI: 16.79–19.75) excess cases per 100,000 in the summer compared to winter (See Appendix 3D for more details).

Extended Exposure Period:

Figures 3-7a and 3-7b present results from the analysis extending the exposure period through September and the corresponding reference period through March (See Appendix Table 3E for more details). Rate ratios and rate differences increased slightly for infants, did not change for young children aged 1–4 years, and slightly decreased for older children aged 5–17 years and adults. By geography, infants in the South were most impacted by extending the time frame. Overall, there were increases in both the rate ratio (3.33, 95% CI: 3.19–3.48) and rate difference (16.96 per 100,000, 95% CI: 16.38–17.54), with each of the three southern divisions experiencing increases in these measures (Appendix Table 3E). Conversely, the effect decreased slightly for infants in the Northeast region and essentially did not change for those in the Midwest or West.

Discussion

This study used U.S. data on laboratory-confirmed nontyphoidal *Salmonella* infections from 2010–2015 to examine whether infants were at increased risk of infection during summer overall and to explore differences by sex, geographic region and serotype. We evaluated how the observed relative and absolute measures of effect among infants compared to those among other age groups.

Overall, infants had an increased rate of salmonellosis during summer compared to winter. There were no noteworthy differences in the effect among infants by sex, but there were differences by geography. Infants in the South region and corresponding divisions had higher rate ratios and rate differences than infants in other areas of the country. Compared to the other age groups, infants had similar rate ratios, but higher rate differences across strata. While all age groups were 2–3 times more likely to be infected during summer compared to winter, the impact on infants was greater as there were more excess cases in this age group. Moreover, the R(I) reflecting the joint effect of summer and living in the South region was highest among infants, with 11.27 excess infections per 100,000. These findings might represent a differential impact of higher summer temperatures in the South on infants (Figure 3-1), and may suggest greater vulnerability among infants to future temperature increases. However, because season was used as a proxy for temperature in our study, it would be inappropriate to infer causal interaction (VanderWeele 2009). Future studies using actual temperature measurements as the exposure would be useful for exploring this observation further.

Our finding of increased rates of salmonellosis during the warm season is consistent with previous findings in the U.S. and other parts of the world (D’Souza et al 2004; Kovats et al. 2004; Fleury et al. 2006; Naumova et al. 2007; Lake et al. 2009; Britton et al. 2010; Kendrovski et al. 2011; Lal et al. 2012; Akil et al. 2014; Jiang et al. 2015). While it is well established that incidence of *Salmonella* infection in the U.S. exhibits seasonality with peaks in summer, variation in seasonal patterns by age and other factors simultaneously is less studied (CDC 2018). Such information could be useful in better understanding the potential impact of increases in temperature due to climate change on various populations.

When individual serotypes were examined, rates of infection for most increased during summer compared to winter across age groups. The few prior studies examining the association between temperature and select individual *Salmonella* serotypes have reported positive associations with Enteritidis and Typhimurium (Kovats et al. 2004; Lake et al 2009; Milazzo et al. 2016). A study by Kovats et al. (2004) in Europe found the strongest associations of environmental temperature among persons aged 15–64 years and with Enteriditis infections, which were thought to be primarily foodborne. However, apart from Typhimurium, the authors did not report on other *Salmonella* serotypes individually, and they did not separate infants from other young children. Nevertheless, these findings led the authors to surmise that the effect of temperature on salmonellosis is more strongly mediated by food storage and handling practices and less by non-food sources. In our study, rates of infection with serotype Enteritidis were higher in summer compared to winter, especially among adults, but the association was not as strong as for other serotypes.

Three serotypes with notably higher rates in summer were Javiana, Newport, and Muenchen. Compared to other age groups, infants had similar rate ratios for these three serotypes, but greater rate differences. These are three relatively common serotypes, ranking among the top ten overall in our data, and top five for infants. According to CDC, rates of infection with these three serotypes have been on the rise in recent years, particularly among children aged 0–4 (CDC 2013; CDC 2018). While we did not have information on source of infection, serotypes Javiana and Muenchen have been previously linked to environmental sources such as reptiles, amphibians and water supplies (Haley et al. 2009; Clarkson et al. 2010; McEgan et al. 2014; CDC 2015; Mauer et al. 2015). Serotype Newport has also been found in water supplies, including those used to irrigate fresh produce, although outbreaks with this serotype have been traced to a broad range of food items (Greene et al. 2007; CDC 2013; McEgan et al. 2014). Another serotype worth noting, Rubislaw, impacted infants in our study more than other age groups, especially in summer. Compared to the three serotypes discussed above, Rubislaw was relatively rare, ranking 34th overall and accounting for 0.4% of all *Salmonella* infections. It was more common among infants, ranking 10th and accounting for 2.1% of infections. Rubislaw infections from contact with reptiles have been documented (Moffat et al. 2010), and this serotype was found to be prevalent in water supplies and wildlife in the southeastern U.S. (Haley et al. 2009; McEgan et al. 2014; Mauer et al. 2015). Our findings suggest a positive association between ambient temperature and infection with serotypes from environmental, non-food sources, especially among infants, but additional studies are needed to explore this hypothesis.

Having a clearer understanding of transmission pathways for *Salmonella* serotypes impacting infants and how they might be affected by temperature would be useful in devising prevention strategies.

Because incidence and invasiveness of salmonellosis have been shown to vary by infant age, we conducted a secondary analysis to explore the primary study question by age subgroups of infants (Cheng et al. 2013). Findings showed generally similar relative and absolute measures of comparison across the groups, across strata. We did not examine individual serotypes in this secondary analysis, but future studies of temperature and infection with specific *Salmonella* serotypes might consider stratified analysis by infant age to detect any nuances.

When we extended the exposure period to include September, infants in the South were most impacted. Prior studies reporting increases in salmonellosis associated with ambient temperature one to five weeks prior to illness onset have attributed the ‘lag’ to possible contamination upstream in the food chain (D’Souza et al. 2004; Kovats et al. 2004; Naumova et al. 2007; Lake et al. 2009). While this might apply to older age groups, it is a less plausible explanation for our findings among infants as contaminated food is not likely the primary source of infection in this age group. Also, we did not observe increases in the effect among infants in the other three census regions. Rather than a delay in cases related to high August temperatures, the observed increased effect among infants in the South might be driven by high September temperatures in the region (Figure 1). In the three southern states of Mississippi, Tennessee, and Alabama, Akil et al. (2014) found highest numbers of *Salmonella* infections from July through September and a strong positive correlation between infection and monthly temperature.

There are several limitations to note. First, LEDS is likely an undercount of the true number of salmonellosis cases. Sick persons may not seek medical care, healthcare providers may not order appropriate tests, or the results may not be reported to the health department (CDC 2011). An estimated 29.3 cases of salmonellosis occur for every one that is laboratory confirmed (Scallan et al. 2011; CDC 2013). Importantly, this may vary by age group. For instance, sick infants may be more likely to receive medical care, and in a clinical setting, may be more likely to be tested for *Salmonella* than adults. In this case, the rate for adults may be artificially low. However, as long as the underrecognition and underreporting are consistent throughout the year (i.e., not associated with season/temperature), this should not impact our findings by age group (Kovats et al. 2004). Furthermore, because LEDS is a passive surveillance system, reporting of confirmed isolates by states varies somewhat year to year. However, Chai et al. (2012) found that from 2004–2009, the annual incidence rates of reported infection with the most common serotype of *Salmonella* (Enteritidis) for the ten FoodNet states were similar for LEDS and FoodNet, which is considered more comprehensive since it is active surveillance.

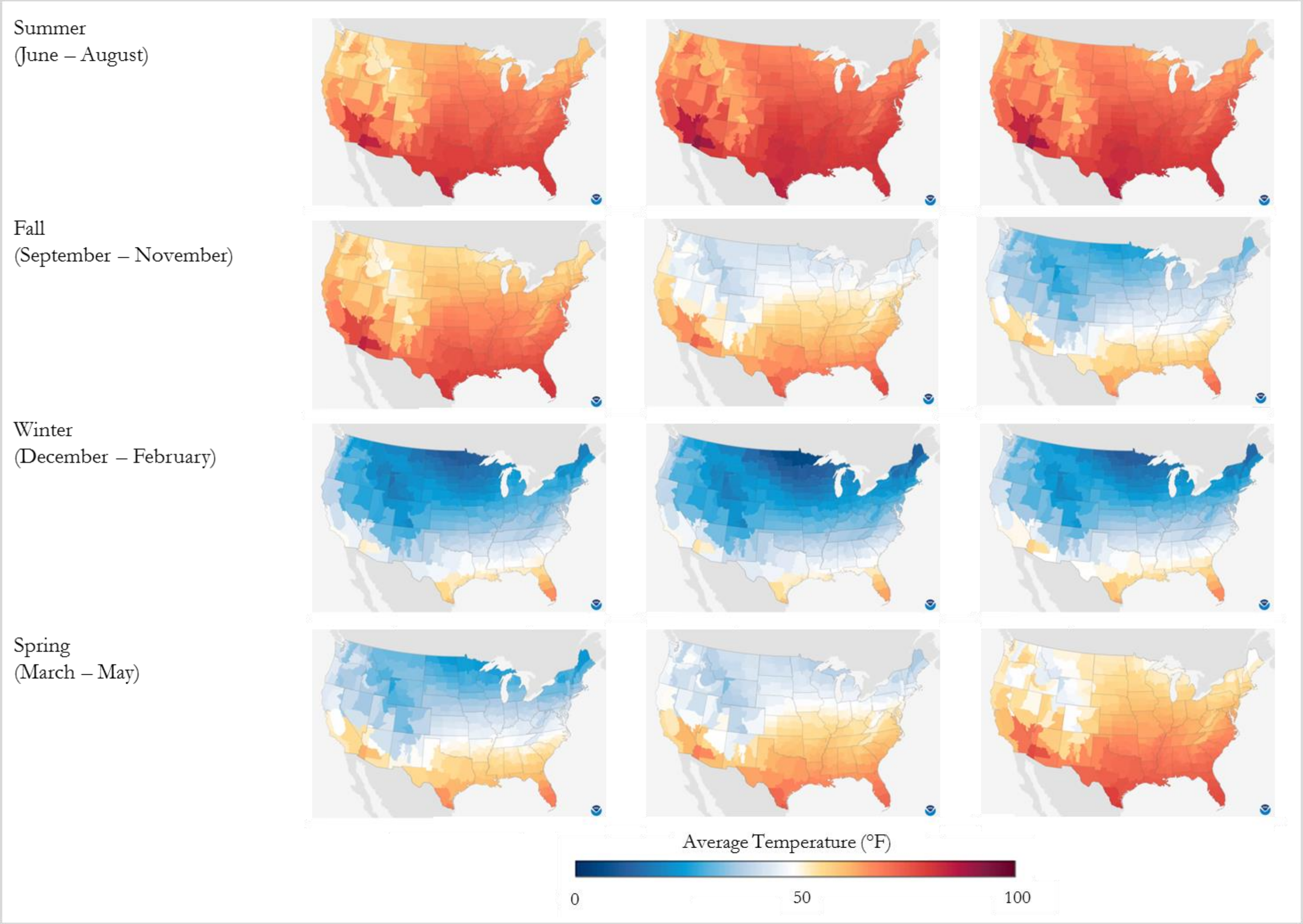
Missing data limited our stratified analyses. While the percent of missing values for several key study variables was low, the majority of isolates were missing information on race and ethnicity. Therefore, we were not able to evaluate effect measure modification by these variables. Previous studies in the U.S. have found differences in salmonellosis by race and ethnicity overall and among infants (Arshad et al. 2007; Jones et al. 2008; Cheng et al. 2013). Cheng et al. (2013) found increased rates of infection among Black, Asian and Hispanic infants, compared to White infants, and that invasive disease was more common in Black and Asian infants. It is unclear whether we would expect the effect of interest in this study to vary by race/ethnicity, but future studies evaluating temperature and salmonellosis should consider these variables.

Next, we examined the effect of summer on rates of the forty most common *Salmonella* serotypes that accounted for about 90% of infections. As such, it is possible that we missed a serotype that is less common, but more likely to impact infants in summer. It may also be that those rare serotypes accounting for the remaining 10% of infections are not as important in the summer. In their recent study, Judd et al. (2019) found that *Salmonella* serotype diversity in the U.S. varied geographically and was greatest among infants, but that rare serotypes were more frequently reported in winter than summer. Further research using additional years of LEDS data would allow examination of the effect of summer on less common serotypes stratified by age and geographic region simultaneously.

Lastly, there were limitations related to our exposure measure. In this study, we used date of specimen collection in lieu of date of exposure or date of illness onset. However, we do not expect this to impact our conclusions since the delay between these dates is likely days and we used three-month time intervals (Kovats et al. 2004). Next, we could not exclude travel-associated cases that were unlikely due to local ambient temperature, but these likely made up only a small proportion of cases (Jones et al. 2006; Kendall et al. 2012). We also could not exclude outbreak-associated cases that might have a different relationship with temperature than sporadic cases (Kovats et al. 2004). However, the vast majority of salmonellosis cases, especially among infants, are thought to be sporadic in nature (Haddock 1993; Olsen et al. 2000). Finally, we used a temperature-based definition of season rather than actual temperature measurements as our exposure, which is less precise. However, D'Souza et al. (2004) found that, in the five Australian cities included in their study, average monthly temperature explained the seasonal variation in salmonellosis notifications. Furthermore, temperature has been shown to be a key predictor of salmonellosis. Other meteorological factors like precipitation (Akil et al. 2014) and relative humidity (Kovats et al. 2004; Zhang et al. 2012) are considered less important, although Jiang et al. (2015) reported a positive association between extreme precipitation events and salmonellosis risk in Maryland, especially near the coast.

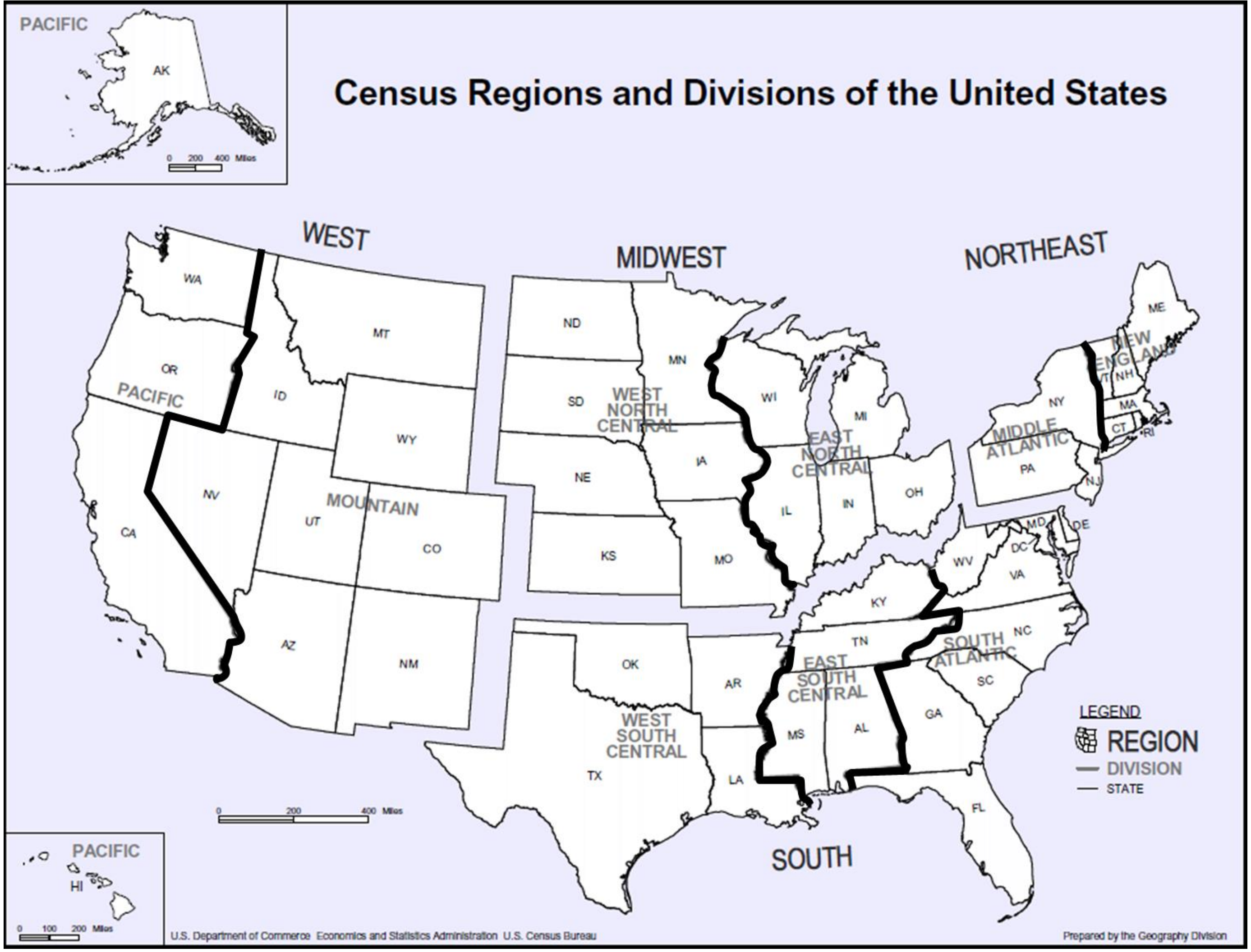
In conclusion, this study confirmed that infants are at increased risk of salmonellosis in summer compared to winter. Across strata, the absolute effect among infants exceeded that of any other age group, although relative effects were similar. This was especially true in the South and for serotypes commonly from environmental, non-food sources. Together, results revealed a greater impact on infants and suggest enhanced vulnerability of this group to increases in temperature. Our findings serve as a baseline for future studies examining the potential impact of ambient temperature on *Salmonella* incidence by age, geographic region and serotype in the U.S.

Figure 3-1. Average monthly ambient temperature (ºF) across the contiguous United States by month and season, 1981–2010.



Source: National Oceanic and Atmospheric Administration. Available: https://www.climate.gov/maps-data/data-snapshots/averagetemp-monthly-1981-2010-cmb-0000-12-00?theme=Temperature, Accessed 6/1/2019.

Figure 3-2. U.S. Census regions and divisions



Source: U.S. Census Bureau. Available: https://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf, Accessed 6/1/2019

Table 3-1a. Cases of nontyphoidal salmonellosis cases by age group and select characteristics, U.S., Laboratory-based Enteric Disease Surveillance, 2010–2015

	Age group											
	Total Cases		Infants (< 1 year)		1–4 years		5–17 years		≥18 years		Age Missing	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Total	264908	100.0	26564	100.0	39166	100.0	38902	100.0	156920	100.0	3356	100.0
Sex												
Female	132653	50.1	11634	43.8	17768	45.4	17076	43.9	85092	54.2	1083	32.3
Male	119296	45.0	13420	50.5	19463	49.7	20160	51.8	65257	41.6	996	29.7
Missing	12959	4.9	1510	5.7	1935	4.9	1666	4.3	6571	4.2	1277	38.1
Race												
American Indian/ Alaska Native	1064	0.4	105	0.4	99	0.3	149	0.4	711	0.5	5	0.2
Asian/Pacific Islander	3208	1.2	357	1.3	747	1.9	578	1.5	1521	1.0	0	0.0
Black/African American	12465	4.7	1561	5.9	2722	7.0	1731	4.5	6414	4.1	37	1.1
White	80261	30.3	8882	33.4	10721	27.4	11194	28.8	49253	31.4	211	6.3
Missing	167910	63.4	15659	59.0	24877	63.5	25250	64.9	99021	63.1	3103	92.5
Hispanic ethnicity												
Hispanic	5646	2.1	810	3.1	1172	3.0	1164	3.0	2493	1.6	7	0.2
Non-Hispanic	51608	19.5	4782	18.0	6814	17.4	6939	17.8	33015	21.0	58	1.7
Missing	207654	78.4	20972	79.0	31180	79.6	30799	79.2	121412	77.4	3291	98.1
Census Region												
Northeast	46173	17.4	3251	12.2	6087	15.5	6666	17.1	29470	18.8	699	20.8
Midwest	48496	18.3	2804	10.6	4627	11.8	6493	16.7	33767	21.5	805	24.0
South	119252	45.0	17095	64.4	21724	55.5	17066	43.9	62228	39.7	1139	33.9
West	50981	19.2	3413	12.9	6728	17.2	8677	22.3	31450	20.0	713	21.3
Missing	6	0.0	1	0.0	0	0.0	0	0.0	5	0.0	0	0.0

Table 3-1a (cont).

	Total Cases		Age group								Age Missing	
			Infants (< 1 year)		1–4 years		5–17 years		≥18 years			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Census Division												
New England	11852	4.5	561	2.1	1121	2.9	1515	3.9	8595	5.5	60	1.8
Middle Atlantic	34321	13.0	2690	10.1	4966	12.7	5151	13.2	20875	13.3	639	19.0
East North Central	30060	11.4	1598	6.0	2657	6.8	4049	10.4	21413	13.7	343	10.2
West North Central	18436	7.0	1206	4.5	1970	5.0	2444	6.3	12354	7.9	462	13.8
South Atlantic	58034	21.9	7559	28.5	10283	26.3	8077	20.8	31303	20.0	812	24.2
East South Central	19908	7.5	2621	9.9	3646	9.3	2757	7.1	10698	6.8	186	5.5
West South Central	41310	15.6	6915	26.0	7795	19.9	6232	16.0	20227	12.9	141	4.2
Mountain	16807	6.3	1352	5.1	1990	5.1	2735	7.0	10649	6.8	81	2.4
Pacific	34174	12.9	2061	7.8	4738	12.1	5942	15.3	20801	13.3	632	18.8
Missing	6	0.0	1	0.0	0	0.0	0	0.0	5	0.0	0	0.0
Month												
January	12807	4.8	1332	5.0	1889	4.8	1864	4.8	7518	4.8	204	6.1
February	10153	3.8	1006	3.8	1372	3.5	1424	3.7	6204	4.0	147	4.4
March	13032	4.9	1169	4.4	1746	4.5	1822	4.7	8094	5.2	201	6.0
April	17220	6.5	1538	5.8	2446	6.3	2596	6.7	10393	6.6	247	7.4
May	21126	8.0	1930	7.3	3027	7.7	3109	8.0	12740	8.1	320	9.5
June	27454	10.4	2484	9.4	3991	10.2	4035	10.4	16587	10.6	357	10.6
July	35189	13.3	3167	11.9	5047	12.9	5302	13.6	21126	13.5	547	16.3
August	37433	14.1	3664	13.8	5621	14.4	5830	15.0	21938	14.0	380	11.3
September	32696	12.3	3657	13.8	5078	13.0	4876	12.5	18811	12.0	274	8.2
October	26343	9.9	3192	12.0	4398	11.2	3805	9.8	14685	9.4	263	7.8
November	17841	6.7	2066	7.8	2648	6.8	2390	6.1	10521	6.7	216	6.4
December	13614	5.1	1359	5.1	1903	4.9	1849	4.8	8303	5.3	200	6.0

Table 3-1a (cont).

			Age group									
	Total Cases		Infants (< 1 year)		1–4 years		5–17 years		≥18 years		Age Missing	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Year												
2010	43815	16.5	4557	17.2	7245	18.5	6529	16.8	24496	15.6	988	29.4
2011	43417	16.4	4548	17.1	6960	17.8	6695	17.2	24672	15.7	542	16.2
2012	45215	17.1	4751	17.9	6916	17.7	6652	17.1	26329	16.8	567	16.9
2013	41667	15.7	4049	15.2	6160	15.7	6169	15.9	24677	15.7	612	18.2
2014	43730	16.5	4187	15.8	5913	15.1	6380	16.4	26917	17.2	333	9.9
2015	47064	17.8	4472	16.8	5972	15.3	6477	16.7	29829	19.0	314	9.4

Table 3-1b. Number, percentage and rank of nontyphoidal *Salmonella* serotypes by age group, U.S., Laboratory-based Enteric Disease Surveillance, 2010–2015

Age Group							
Infants (< 1 year)				1–4 years			
Serotype	No.	%	Rank	Serotype	No.	%	Rank
Total	26564	100.0		Total	39166	100.0	
Newport	3737	14.1	1	Typhimurium	6859	17.5	1
Typhimurium	2740	10.3	2	Newport	3994	10.2	2
Javiana	2080	7.8	3	Enteritidis	3688	9.4	3
Enteritidis	1316	5.0	4	Javiana	3506	9.0	4
Muenchen	1050	4.0	5	I 4,[5],12:i:-	2273	5.8	5
Montevideo	951	3.6	6	Heidelberg	1337	3.4	6
I 4,[5],12:i:-	755	2.8	7	Montevideo	1024	2.6	7
Infantis	708	2.7	8	Muenchen	839	2.1	8
Heidelberg	644	2.4	9	Mississippi	832	2.1	9
Rubislaw	550	2.1	10	Saintpaul	815	2.1	10
Mississippi	458	1.7	11	Infantis	782	2.0	11
Oranienburg	424	1.6	12	Oranienburg	633	1.6	12
Saintpaul	382	1.4	13	Poona	555	1.4	13
Bareilly	352	1.3	14	Braenderup	437	1.1	14
Poona	310	1.2	15	Schwarzengrund	413	1.1	15
Braenderup	291	1.1	16	Paratyphi B[a]	382	1.0	16
Schwarzengrund	278	1.1	17	Agona	353	0.9	17
Thompson	268	1.0	18	Bareilly	338	0.9	18
Gaminara	265	1.0	19	Thompson	318	0.8	19
Give	227	0.9	20	I 13,23:b:-	294	0.8	20
Anatum	214	0.8	21	Stanley	279	0.7	21
Agona	197	0.7	22	Subspecies I, Group O:4	276	0.7	22
I 13,23:b:-	188	0.7	23	I 4,[5],12:b:-	238	0.6	23
Inverness	170	0.6	24	Adelaide	221	0.6	24
Mbandaka	161	0.6	25	Sandiego	214	0.6	25
Hadar	151	0.6	26	Rubislaw	213	0.5	26
Norwich	149	0.6	27	Berta	208	0.5	27
Subspecies I	137	0.5	28	Subspecies I	179	0.5	28
Subspecies I, Group O:4	137	0.5	29	Norwich	173	0.4	29
Litchfield	135	0.5	30	Panama	166	0.4	30
All other[b]	2927	11.0	31-455	All other[b]	2761	7.1	31-403
Unknown	3207	12.1		Unknown	3546	9.1	

[a] Paratyphi B var. L(+) tartrate+; [b] All other includes other serotyped, partially serotyped and rough, mucoid and/or nonmotile specimen.

Table 3-1b (cont.).

Age Group							
5–17 years				≥18 years			
Serotype	No.	%	Rank	Serotype	No.	%	Rank
Total	38902	100.0		Total	156920	100.0	
Enteritidis	7137	18.4	1	Enteritidis	35641	22.7	1
Typhimurium	6723	17.3	2	Newport	16946	10.8	2
Newport	3250	8.4	3	Typhimurium	16878	10.8	3
Javiana	2603	6.7	4	Javiana	8138	5.2	4
I 4,[5],12:i:-	2267	5.8	5	I 4,[5],12:i:-	6189	3.9	5
Heidelberg	1300	3.3	6	Infantis	4227	2.7	6
Saintpaul	836	2.2	7	Heidelberg	3721	2.4	7
Infantis	740	1.9	8	Muenchen	3351	2.1	8
Montevideo	739	1.9	9	Montevideo	3315	2.1	9
Oranienburg	691	1.8	10	Saintpaul	3199	2.0	10
Braenderup	603	1.6	11	Braenderup	2996	1.9	11
Thompson	548	1.4	12	Thompson	2613	1.7	12
Poona	523	1.3	13	Oranienburg	2584	1.7	13
Mississippi	502	1.3	14	Bareilly	1803	1.2	14
Paratyphi B[a]	466	1.2	15	Agona	1473	0.9	15
Muenchen	462	1.2	16	Paratyphi B[a]	1453	0.9	16
Subspecies I, GroupO:4	313	0.8	17	Mississippi	1428	0.9	17
Bareilly	278	0.7	18	Anatum	1303	0.8	18
Berta	273	0.7	19	Berta	1273	0.8	19
I 4,[5],12:b:-	264	0.7	20	Poona	1011	0.6	20
Stanley	252	0.7	21	Subspecies I, Group O:4	895	0.6	21
Agona	251	0.7	22	Hadar	879	0.6	22
Sandiego	226	0.6	23	Hartford	871	0.6	23
I 13,23:b:-	208	0.5	24	Litchfield	841	0.5	24
Schwarzengrund	197	0.5	25	I 4,[5],12:b:-	791	0.5	25
Panama	193	0.5	26	Mbandaka	791	0.5	26
Subspecies I	176	0.5	27	Senftenberg	775	0.5	27
Hartford	170	0.4	28	Dublin	754	0.5	28
Norwich	150	0.4	29	Norwich	738	0.5	29
Litchfield	127	0.3	30	I 13,23:b:-	685	0.4	30
All other[b]	2445	6.3	31-404	All other[b]	13770	8.8	31-783
Unknown	3069	7.9		Unknown	10002	6.4	

[a] Paratyphi B var. L(+) tartrate+; [b] All other includes other serotyped, partially serotyped and rough, mucoid and/or nonmotile specimen.

Table 3-2. Incidence rates per 100,000 population of nontyphoidal salmonellosis by age group and select characteristics, 2010–2015

	Age group									
	Infants (< 1 year)					1–4 years				
	No. of Cases	Population	Rate	95% CI		No. of Cases	Population	Rate	95% CI	
Overall^{a}	26564	23728308	111.95	110.60	113.30	39166	96314118	40.66	40.26	41.07
Sex										
Female	11634	11594607	100.34	98.52	102.16	17768	47108639	37.72	37.16	38.27
Male	13420	12133702	110.60	108.73	112.47	19463	49205479	39.55	39.00	40.11
Census Region										
Northeast	3251	3815575	85.20	82.27	88.13	6087	15408054	39.51	38.51	40.50
Midwest	2804	4996524	56.12	54.04	58.20	4627	20409833	22.67	22.02	23.32
South	17095	9072806	188.42	185.60	191.24	21724	36778822	59.07	58.28	59.85
West	3413	5818545	58.66	56.69	60.63	6728	23640103	28.46	27.78	29.14
Census Division										
New England	561	911259	61.56	56.47	66.66	1121	3760200	29.81	28.07	31.56
Middle Atlantic	2690	2904316	92.62	89.12	96.12	4966	11647854	42.63	41.45	43.82
East North Central	1598	3368437	47.44	45.11	49.77	2657	13803748	19.25	18.52	19.98
West North Central	1206	1628087	74.07	69.89	78.26	1970	6606085	29.82	28.50	31.14
South Atlantic	7559	4433111	170.51	166.67	174.36	10283	18001851	57.12	56.02	58.23
East South Central	2621	1394004	188.02	180.82	195.22	3646	5681078	64.18	62.09	66.26
West South Central	6915	3245691	213.05	208.03	218.07	7795	13095893	59.52	58.20	60.84
Mountain	1352	1847687	73.17	69.27	77.07	1990	7587582	26.23	25.07	27.38
Pacific	2061	3970858	51.90	49.66	54.14	4738	16052521	29.52	28.68	30.36

Table 3-2 (cont.).

	Age group									
	5–17 years					≥18 years				
	No. of Cases	Population	Rate	95% CI		No. of Cases	Population	Rate	95% CI	
Overall[a]	38902	322577309	12.06	11.94	12.18	156920	1447792403	10.84	10.78	10.89
Sex										
Female	17076	157729158	10.83	10.66	10.99	85092	743958801	11.44	11.36	11.51
Male	20160	164848155	12.23	12.06	12.40	65257	703833624	9.27	9.20	9.34
Census Region										
Northeast	6666	53340585	12.50	12.20	12.80	29470	262575966	11.22	11.10	11.35
Midwest	6493	69672189	9.32	9.09	9.55	33767	309494410	10.91	10.79	11.03
South	17066	121922157	14.00	13.79	14.21	62228	539610138	11.53	11.44	11.62
West	8677	77645020	11.18	10.94	11.41	31450	336474185	9.35	9.24	9.45
Census Division										
New England	1515	13738426	11.03	10.47	11.58	8595	69196049	12.42	12.16	12.68
Middle Atlantic	5151	39602159	13.01	12.65	13.36	20875	193379917	10.79	10.65	10.94
East North Central	4049	48089793	8.42	8.16	8.68	21413	214393138	9.99	9.85	10.12
West North Central	2444	21582396	11.32	10.88	11.77	12354	95101272	12.99	12.76	13.22
South Atlantic	8077	60344677	13.38	13.09	13.68	31303	286393334	10.93	10.81	11.05
East South Central	2757	19114083	14.42	13.89	14.96	10698	85828585	12.46	12.23	12.70
West South Central	6232	42463397	14.68	14.31	15.04	20227	167388219	12.08	11.92	12.25
Mountain	2735	24828260	11.02	10.60	11.43	10649	102355594	10.40	10.21	10.60
Pacific	5942	52816760	11.25	10.96	11.54	20801	234118591	8.88	8.76	9.01

[a] Strata totals might not add to Overall total due to missings.

Figure 3-3. a.) Six-year average monthly incidence rate per 100,000 population of nontyphoidal salmonellosis by age group, 2010–2015; b.) Average annual incidence rate per 100,000 population of nontyphoidal salmonellosis by age group, 2010–2015

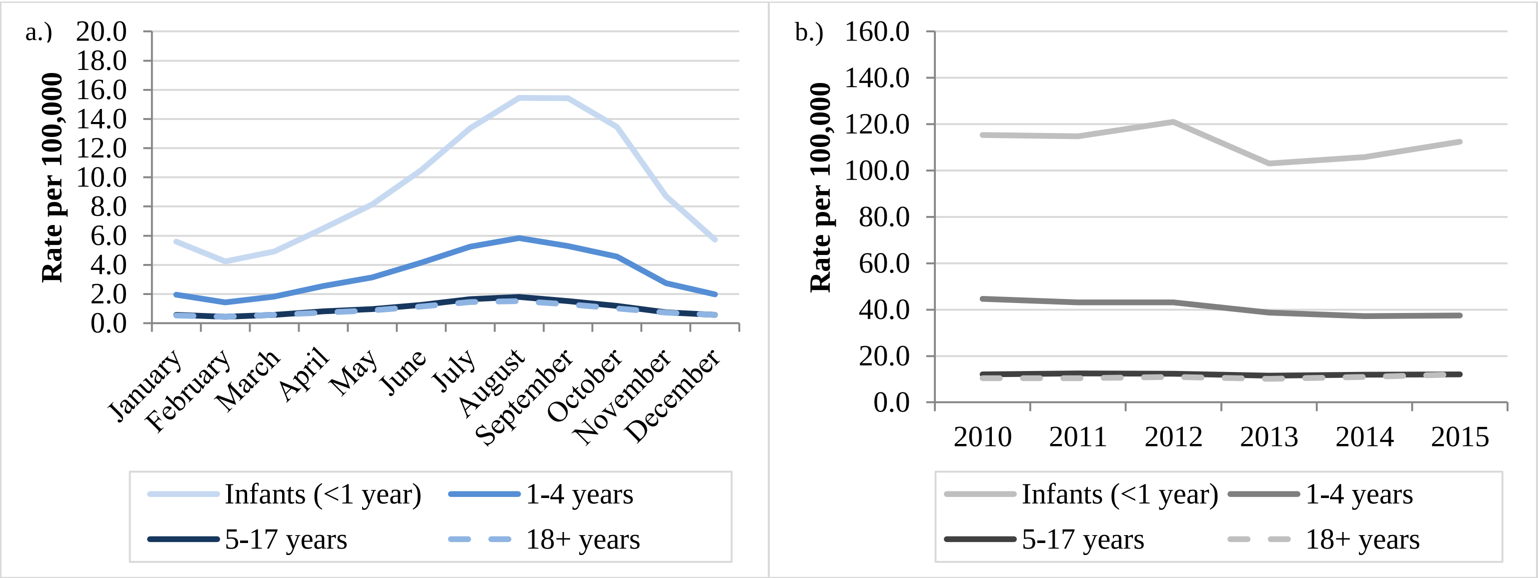


Figure 3-4a. Rate ratios and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by age group, sex, and U.S. Census region, 2010–2015.

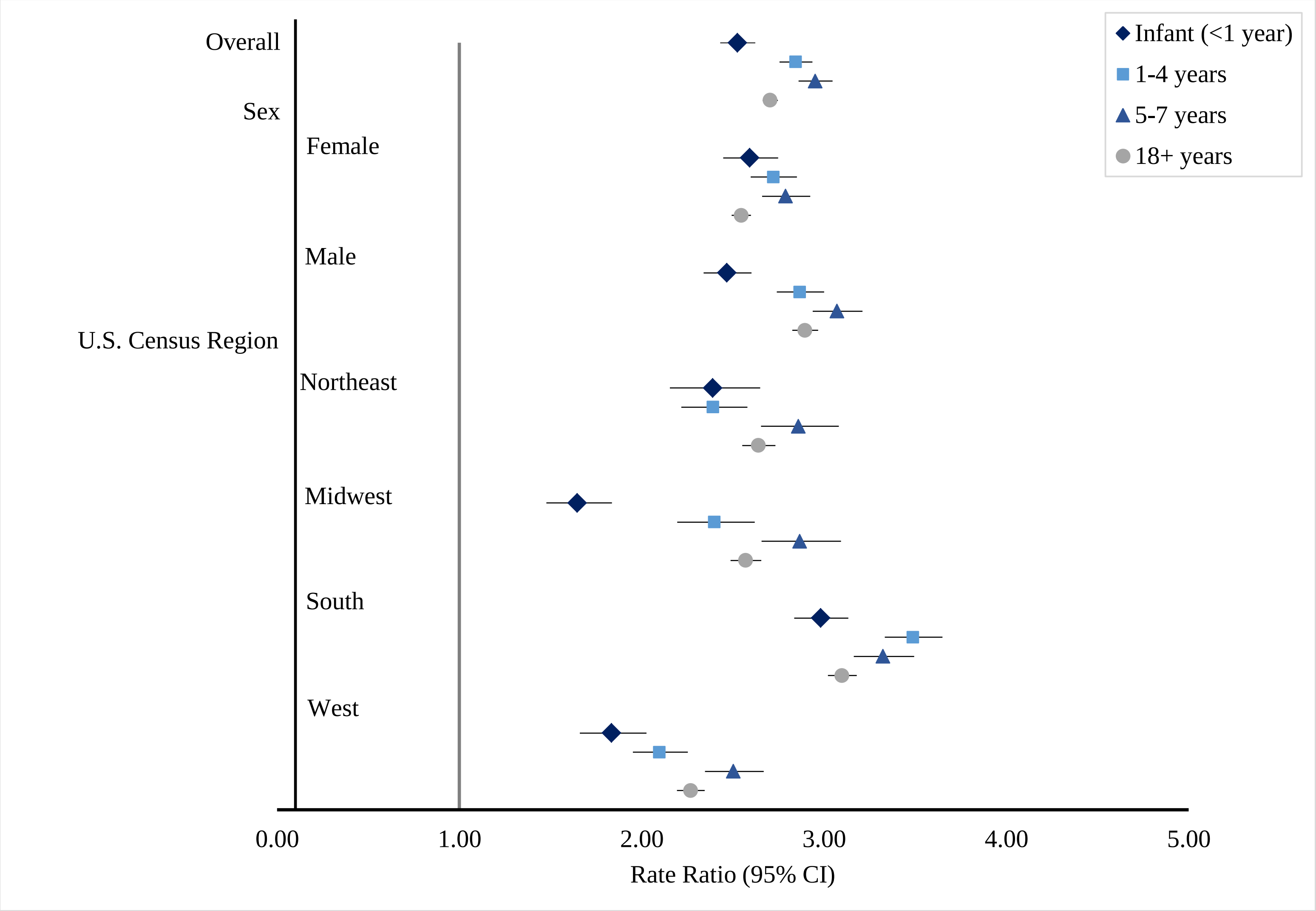


Figure 3-4b. Rate differences and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by age group, sex, and U.S. Census region, 2010–2015.

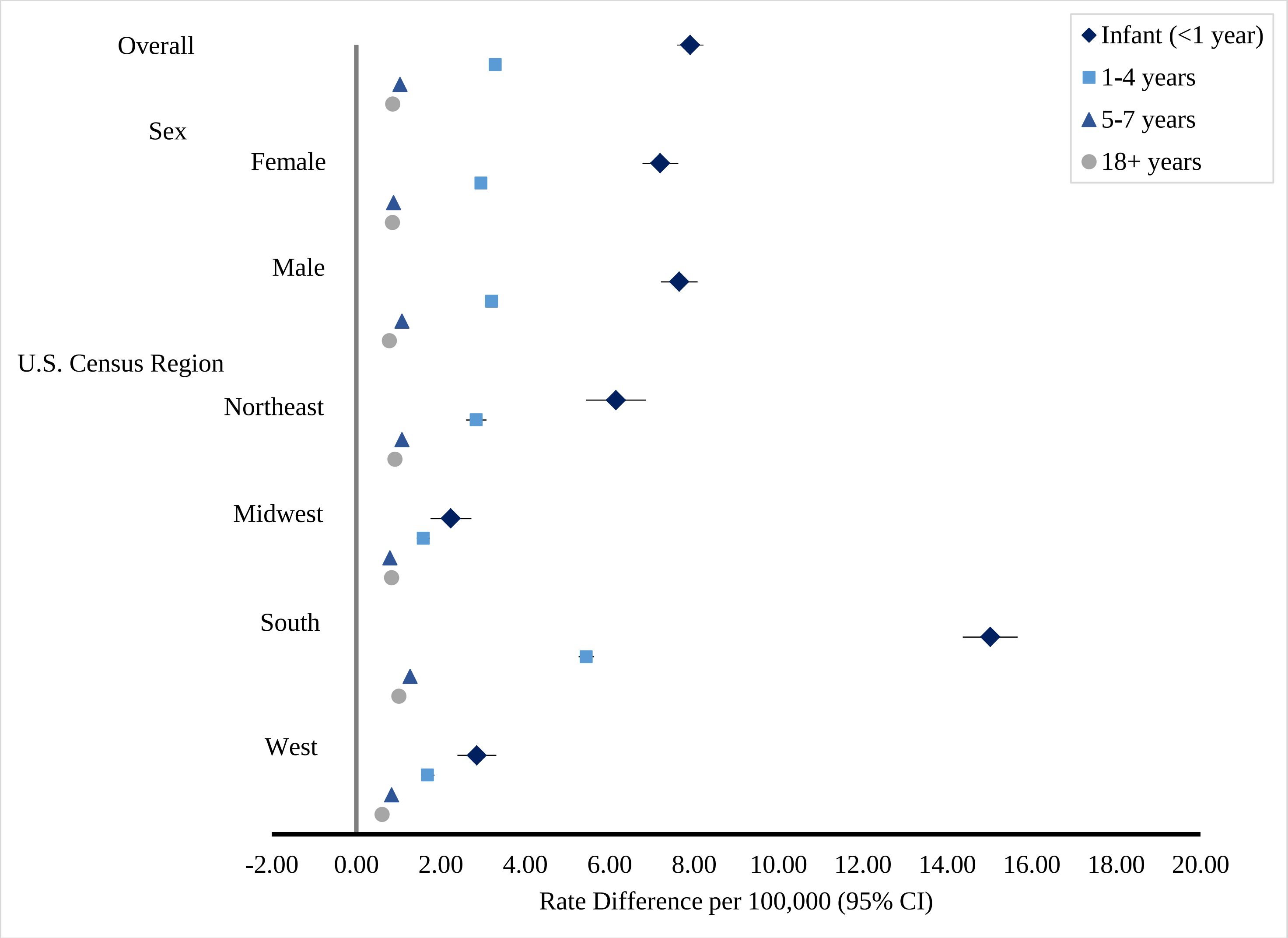


Figure 3-4c. Rate ratios and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by age group and U.S. Census division, 2010–2015.

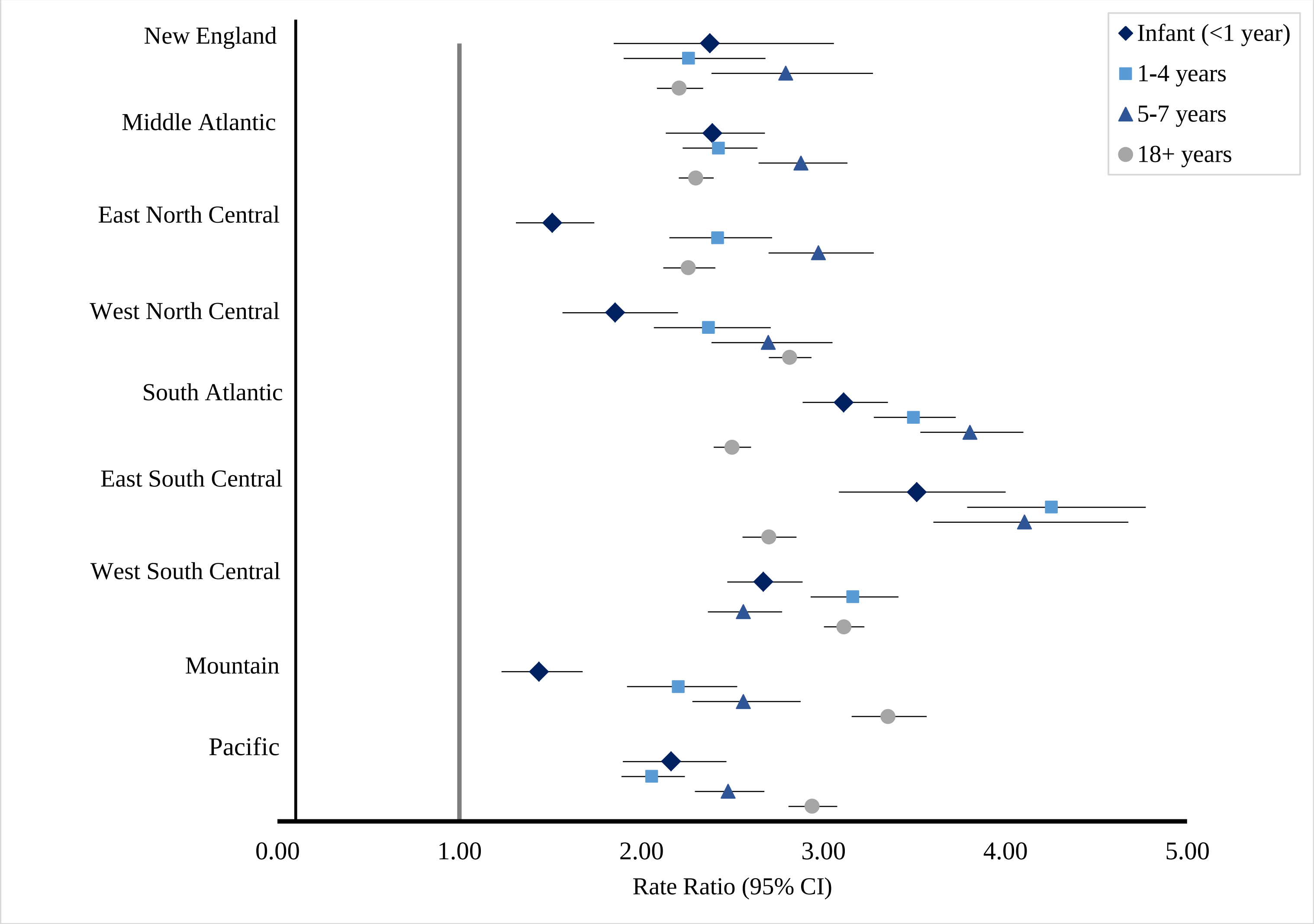


Figure 3-4d. Rate differences and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by age group and U.S. Census division, 2010–2015.

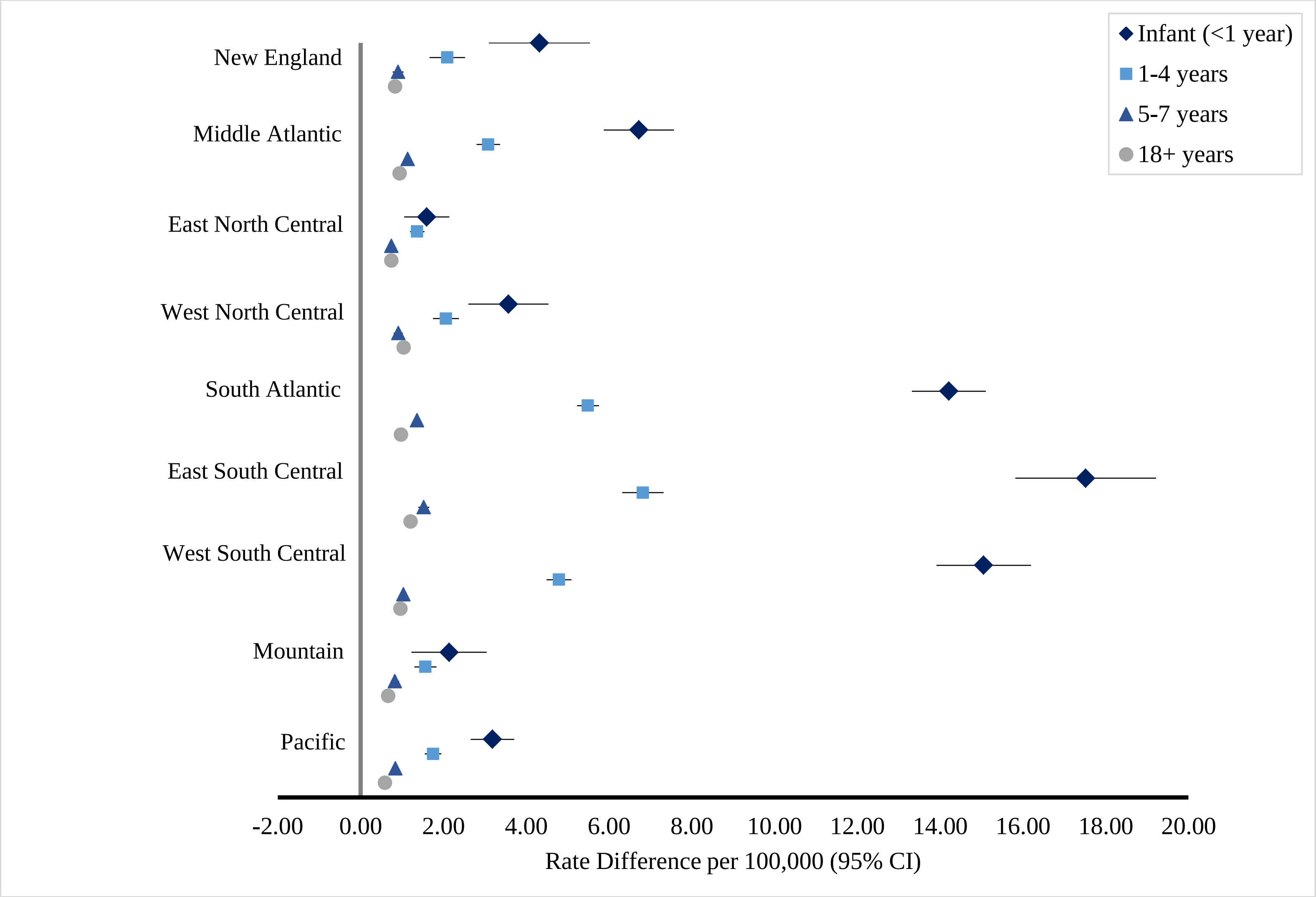


Table 3-3. Rate due to interdependence (R(I)) assessing joint effects of season and U.S. Census region

	Rates per 100,000							
	Infants (< 1 year)		1–4 years		5–17 years		≥18 years	
	Summer (E+)	Winter (E-)	Summer (E+)	Winter (E-)	Summer (E+)	Winter (E-)	Summer (E+)	Winter (E-)
Region								
Northeast (1)	10.58	4.43	4.89	2.04	1.67	0.58	1.48	0.56
Midwest (2)	5.71	3.47	2.73	1.14	1.23	0.43	1.37	0.53
South (3)	22.60	7.58	7.64	2.19	1.83	0.55	1.50	0.48
West (4)	6.28	3.42	3.23	1.54	1.40	0.56	1.10	0.48
Average (1,2,4)	7.52	3.77	3.62	1.58	1.43	0.52	1.32	0.53

R(I): Summer (vs. winter) and South region (vs. average for other regions) by age group

Age group	Infants (< 1 year)	1–4 years	5–17 years	≥18 years
R(I)	11.27	3.41	0.37	0.22

Table 3-4a. Rate ratios (RR)[a] and 95% confidence intervals (CI) comparing summer and winter incidence of nontyphoidal salmonellosis by serotype and age group, 2010–2015

	Infants (< 1 year)			1–4 years			5–17 years			≥18 years		
Serotype[b]	RR	95% CI		RR	95% CI		RR	95% CI		RR	95% CI	
Agona	-	-	-	2.57	1.87	3.53	2.49	1.72	3.61	2.06	1.77	2.39
Anatum	1.29	0.86	1.93	-	-	-	-	-	-	2.20	1.87	2.59
Bareilly	4.13	2.84	6.00	-	-	-	3.14	2.15	4.60	3.20	2.73	3.75
Berta	-	-	-	-	-	-	3.05	2.12	4.40	2.90	2.44	3.45
Braenderup	1.58	1.12	2.22	2.84	2.07	3.88	2.90	2.25	3.74	2.49	2.23	2.78
Enteritidis	1.75	1.48	2.05	2.04	1.85	2.24	2.30	2.15	2.47	2.48	2.40	2.56
Heidelberg	1.23	0.98	1.53	1.97	1.68	2.30	2.25	1.93	2.64	2.20	2.00	2.41
I 4,[5],12:b:-	-	-	-	2.97	1.99	4.44	2.50	1.72	3.64	3.30	2.65	4.11
I 4,[5],12:i:-	1.66	1.36	2.03	2.11	1.86	2.39	2.56	2.25	2.91	2.09	1.94	2.25
Infantis	1.66	1.32	2.10	2.31	1.85	2.88	2.60	2.07	3.28	2.33	2.12	2.55
Javiana	5.47	4.63	6.46	6.38	5.57	7.30	6.06	5.20	7.05	5.13	4.74	5.55
Mbandaka	1.28	0.81	2.01	-	-	-	-	-	-	1.64	1.34	2.01
Mississippi	-	-	-	7.78	5.74	10.54	6.49	4.54	9.26	7.37	5.92	9.18
Montevideo	3.61	2.88	4.54	3.10	2.53	3.80	2.74	2.18	3.43	2.74	2.46	3.05
Muenchen	3.74	3.05	4.59	3.66	2.93	4.58	3.70	2.75	4.97	3.11	2.80	3.45
Newport	4.98	4.41	5.62	5.72	5.07	6.46	5.08	4.48	5.77	4.78	4.53	5.05
Oranienburg	1.59	1.22	2.07	3.56	2.71	4.67	3.01	2.39	3.79	2.49	2.22	2.80
Panama	-	-	-	1.36	0.90	2.06	1.92	1.30	2.84	2.30	1.83	2.88
Paratyphi B[a]	-	-	-	1.63	1.18	2.24	3.25	2.39	4.42	2.50	2.11	2.96
Poona	2.07	1.45	2.97	3.23	2.46	4.25	5.22	3.81	7.15	3.51	2.86	4.31
Rubislaw	2.72	2.06	3.60	-	-	-	-	-	-	2.37	1.64	3.43
Saintpaul	2.62	1.92	3.58	1.94	1.57	2.39	2.53	2.06	3.11	2.17	1.95	2.41
Sandiego	-	-	-	1.65	1.13	2.42	2.66	1.77	3.99	1.55	1.22	1.98
Schwarzengrund	2.96	2.07	4.23	3.16	2.36	4.23	3.07	2.01	4.70	2.19	1.75	2.75
Stanley	-	-	-	1.46	1.06	2.00	2.09	1.46	2.98	1.63	1.30	2.04
Subspecies I, Group O:4	-	-	-	2.59	1.76	3.80	1.94	1.40	2.70	2.13	1.76	2.58
Thompson	2.59	1.81	3.72	2.92	2.01	4.25	3.44	2.60	4.56	2.98	2.64	3.37
Typhimurium	1.97	1.76	2.20	2.44	2.27	2.63	3.16	2.92	3.41	2.66	2.54	2.78

[a] Rate ratios not presented when rate numerator averaged fewer than 5 events per year (i.e., <30 across six years), as these are considered statistically unstable https://www.doh.wa.gov/Portals/1/Documents/1500/Rateguide.pdf).

[b] 28 of the 40 most common serotypes for all ages, Laboratory-based Enteric Disease Surveillance, 1996–2015. Results not shown for following 12 serotypes with suppressed rates in three or more age groups: Brandenburg, Derby, Dublin, Give, Hadar, Hartford, Litchfield, Norwich, Seftenberg, Subspecies I, Subspecies I, Group O:7, Subspecies I, Group O:9.

Table 3-4b. Rate differences (RD)[a] per 100,000 and 95% confidence intervals (CI) comparing summer and winter incidence of nontyphoidal salmonellosis by serotype and age group, 2010–2015

	Infants (< 1 year)			1–4 years			5–17 years			≥18 years		
Serotype[b]	RD	95% CI		RD	95% CI		RD	95% CI		RD	95% CI	
Agona	-	-	-	0.03	0.02	0.04	0.01	0.00	0.01	0.01	0.00	0.01
Anatum	0.02	-0.01	0.04	-	-	-	-	-	-	0.01	0.00	0.01
Bareilly	0.15	0.11	0.19	-	-	-	0.01	0.01	0.01	0.01	0.01	0.01
Berta	-	-	-	-	-	-	0.01	0.01	0.01	0.01	0.01	0.01
Braenderup	0.04	0.01	0.08	0.03	0.02	0.04	0.02	0.01	0.02	0.01	0.01	0.02
Enteritidis	0.24	0.17	0.31	0.22	0.19	0.25	0.15	0.14	0.16	0.18	0.17	0.18
Heidelberg	0.05	0.00	0.09	0.08	0.06	0.10	0.03	0.02	0.03	0.02	0.02	0.02
I 4,[5],12:b:-	-	-	-	0.02	0.01	0.03	0.01	0.00	0.01	0.01	0.00	0.01
I 4,[5],12:i:-	0.14	0.09	0.20	0.14	0.12	0.16	0.05	0.05	0.06	0.03	0.02	0.03
Infantis	0.11	0.06	0.15	0.05	0.04	0.06	0.02	0.01	0.02	0.02	0.02	0.02
Javiana	1.03	0.94	1.12	0.45	0.42	0.48	0.10	0.09	0.11	0.07	0.07	0.07
Mbandaka	0.01	-0.01	0.04	-	-	-	-	-	-	0.00	0.00	0.00
Mississippi	-	-	-	0.11	0.10	0.12	0.02	0.02	0.02	0.01	0.01	0.01
Montevideo	0.34	0.29	0.40	0.09	0.07	0.10	0.02	0.01	0.02	0.02	0.02	0.02
Muenchen	0.45	0.39	0.52	0.09	0.08	0.10	0.02	0.01	0.02	0.02	0.02	0.02
Newport	1.76	1.64	1.88	0.50	0.47	0.53	0.12	0.11	0.13	0.14	0.14	0.15
Oranienburg	0.07	0.03	0.12	0.06	0.05	0.07	0.02	0.02	0.02	0.01	0.01	0.02
Panama	-	-	-	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Paratyphi B var. L(+) tartrate+	-	-	-	0.01	0.00	0.02	0.01	0.01	0.02	0.01	0.01	0.01
Poona	0.07	0.03	0.10	0.05	0.04	0.06	0.02	0.02	0.02	0.01	0.01	0.01
Rubislaw	0.16	0.12	0.21	-	-	-	-	-	-	0.00	0.00	0.00
Saintpaul	0.13	0.09	0.16	0.04	0.03	0.06	0.02	0.02	0.02	0.01	0.01	0.02
Sandiego	-	-	-	0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00
Schwarzengrund	0.11	0.08	0.14	0.04	0.03	0.05	0.01	0.00	0.01	0.00	0.00	0.00
Stanley	-	-	-	0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00
Subspecies I, Group O:4	-	-	-	0.02	0.01	0.03	0.01	0.00	0.01	0.00	0.00	0.00
Thompson	0.09	0.06	0.12	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.01	0.02
Typhimurium	0.63	0.53	0.73	0.51	0.47	0.55	0.19	0.18	0.20	0.09	0.09	0.10

[a] Rate differences not presented when rate numerator averaged fewer than 5 events per year (i.e., <30 across six years), as these are considered statistically unstable https://www.doh.wa.gov/Portals/1/Documents/1500/Rateguide.pdf).

[b] 28 of the 40 most common serotypes for all ages, Laboratory-based Enteric Disease Surveillance, 1996–2015. Results not shown for 12 serotypes with suppressed rates in three or more age groups: Brandenburg, Derby, Dublin, Give, Hadar, Hartford, Litchfield, Norwich, Seftenberg, Subspecies I, Subspecies I, Group O:7, Subspecies I, Group O:9

Table 3-5. Incidence rates per 100,000 population of nontyphoidal salmonellosis by infant age group and select characteristics, 2010–2015

	Infant age group									
	<3 months					3–5 months				
	No. of Cases	Population	Rate	95% CI		No. of Cases	Population	Rate	95% CI	
Total[a]	6222	5932077	104.89	102.28	107.49	8291	5932077	139.77	136.76	142.77
Sex										
Female	2712	2898652	93.56	90.04	97.08	3571	2898652	123.20	119.15	127.24
Male	3062	3033426	100.94	97.37	104.52	4276	3033426	140.96	136.74	145.19
Census Region										
Northeast	864	953894	90.58	84.54	96.62	914	953894	95.82	89.61	102.03
Midwest	710	1249131	56.84	52.66	61.02	938	1249131	75.09	70.29	79.90
South	3917	2268202	172.69	167.28	178.10	5421	2268202	239.00	232.64	245.36
West	730	1454636	50.18	46.54	53.82	1018	1454636	69.98	65.68	74.28
Census Division										
New England	115	227815	50.48	41.25	59.71	168	227815	73.74	62.59	84.90
Middle Atlantic	749	726079	103.16	95.77	110.54	746	726079	102.74	95.37	110.12
East North Central	412	842109	48.92	44.20	53.65	529	842109	62.82	57.47	68.17
West North Central	298	407022	73.21	64.90	81.53	409	407022	100.49	90.75	110.22
South Atlantic	1687	1108278	152.22	144.95	159.48	2426	1108278	218.90	210.19	227.61
East South Central	690	348501	197.99	183.22	212.76	810	348501	232.42	216.42	248.43
West South Central	1540	811423	189.79	180.31	199.27	2185	811423	269.28	257.99	280.57
Mountain	302	461922	65.38	58.01	72.75	421	461922	91.14	82.43	99.85
Pacific	428	992715	43.11	39.03	47.20	597	992715	60.14	55.31	64.96

Table 3-5 (cont.).

	Infant age group									
	6–8 months					9–11 months				
	No. of Cases	Population	Rate	95% CI		No. of Cases	Population	Rate	95% CI	
Total[a]	6249	5932077	105.34	102.73	107.95	5802	5932077	97.81	95.29	100.32
Sex										
Female	2847	2898652	98.22	94.61	101.83	2504	2898652	86.38	83.00	89.77
Male	3093	3033426	101.96	98.37	105.56	2989	3033426	98.54	95.00	102.07
Census Region										
Northeast	776	953894	81.35	75.63	87.07	697	953894	73.07	67.64	78.49
Midwest	643	1249131	51.48	47.50	55.45	513	1249131	41.07	37.51	44.62
South	3947	2268202	174.01	168.59	179.44	3810	2268202	167.97	162.64	173.31
West	883	1454636	60.70	56.70	64.71	782	1454636	53.76	49.99	57.53
Census Division										
New England	127	227815	55.75	46.05	65.44	151	227815	66.28	55.71	76.85
Middle Atlantic	649	726079	89.38	82.51	96.26	546	726079	75.20	68.89	81.51
East North Central	377	842109	44.77	40.25	49.29	280	842109	33.25	29.36	37.14
West North Central	266	407022	65.35	57.50	73.21	233	407022	57.25	49.89	64.60
South Atlantic	1764	1108278	159.17	151.74	166.59	1682	1108278	151.77	144.51	159.02
East South Central	575	348501	164.99	151.51	178.48	546	348501	156.67	143.53	169.81
West South Central	1608	811423	198.17	188.48	207.86	1582	811423	194.97	185.36	204.57
Mountain	320	461922	69.28	61.69	76.87	309	461922	66.89	59.44	74.35
Pacific	563	992715	56.71	52.03	61.40	473	992715	47.65	43.35	51.94

Figure 3-5. a.) Six-year average monthly incidence rate per 100,000 population of nontyphoidal salmonellosis by infant age group, 2010–2015; b.) Average annual incidence rate per 100,000 population of nontyphoidal salmonellosis by infant age group, 2010–2015

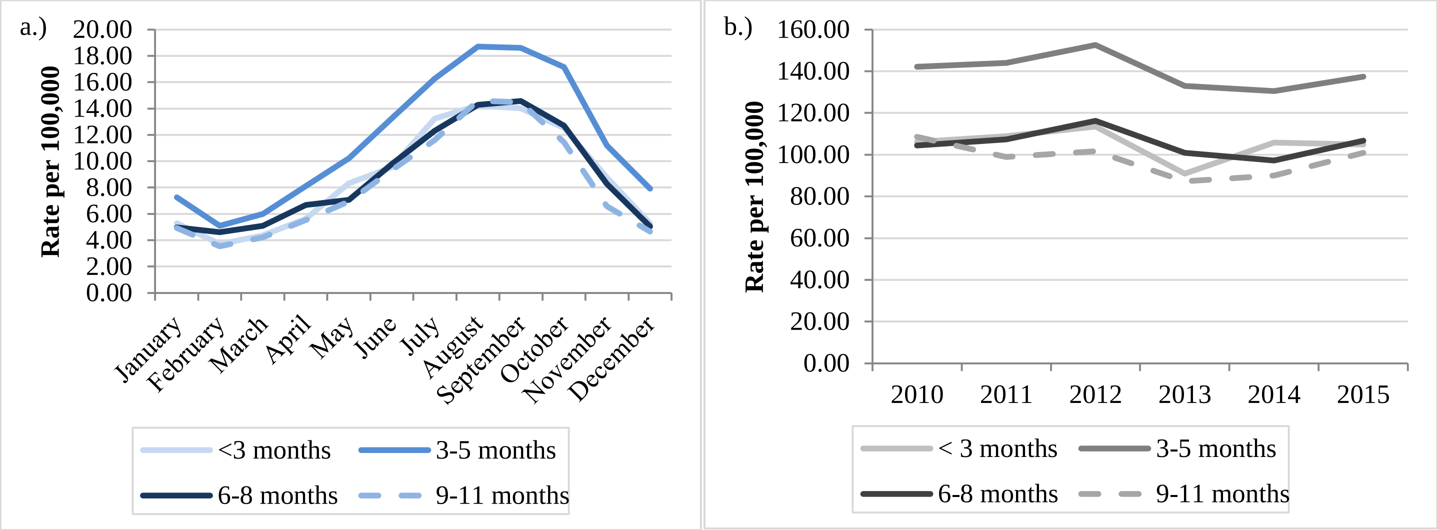


Figure 3-6a. Rate ratios and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by infant age group, sex, and U.S. Census region, 2010–2015

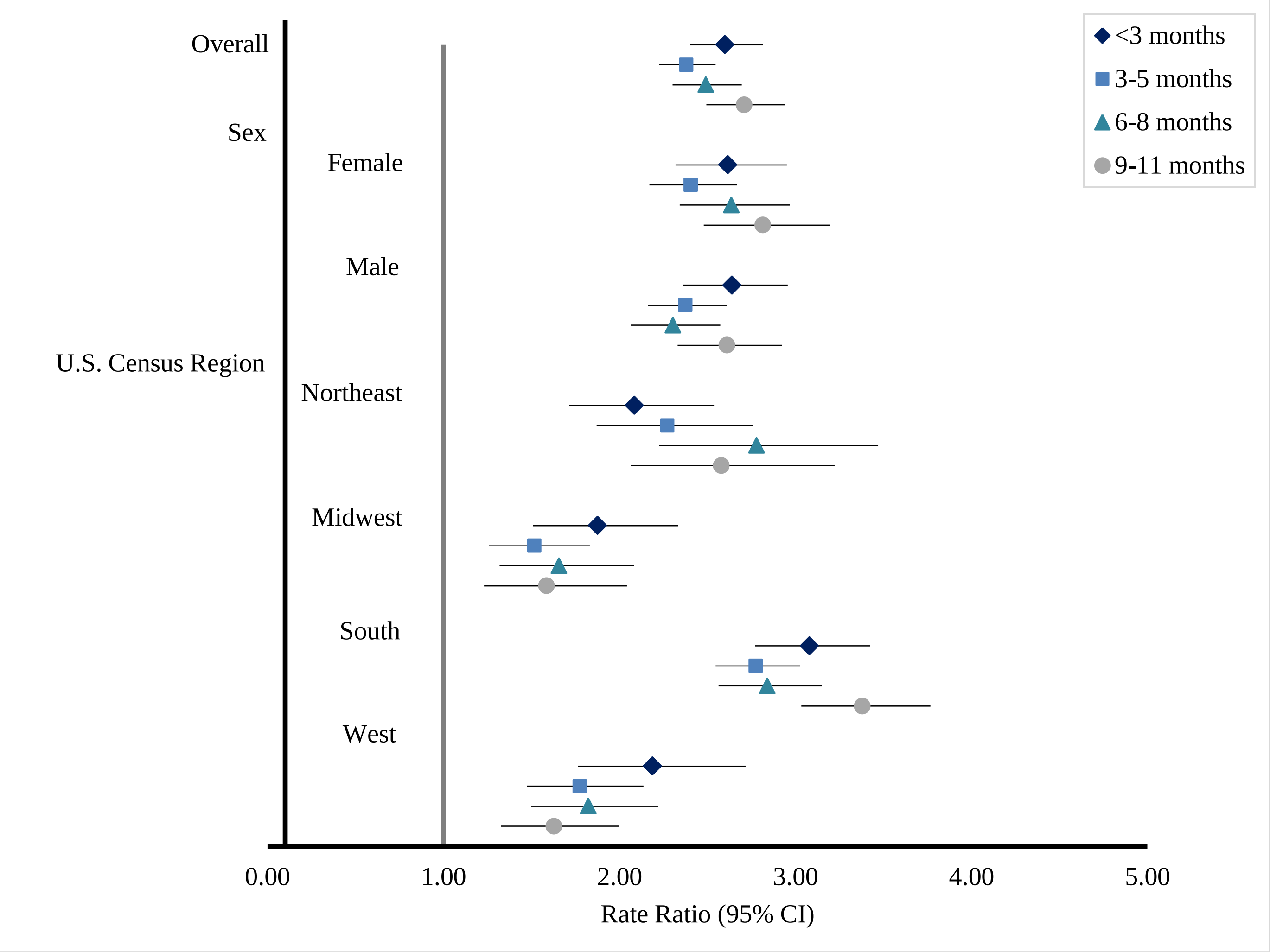


Figure 3-6b. Rate differences and 95% confidence intervals comparing summer and winter incidence of nontyphoidal salmonellosis by infant age group, sex, and U.S. Census region, 2010–2015

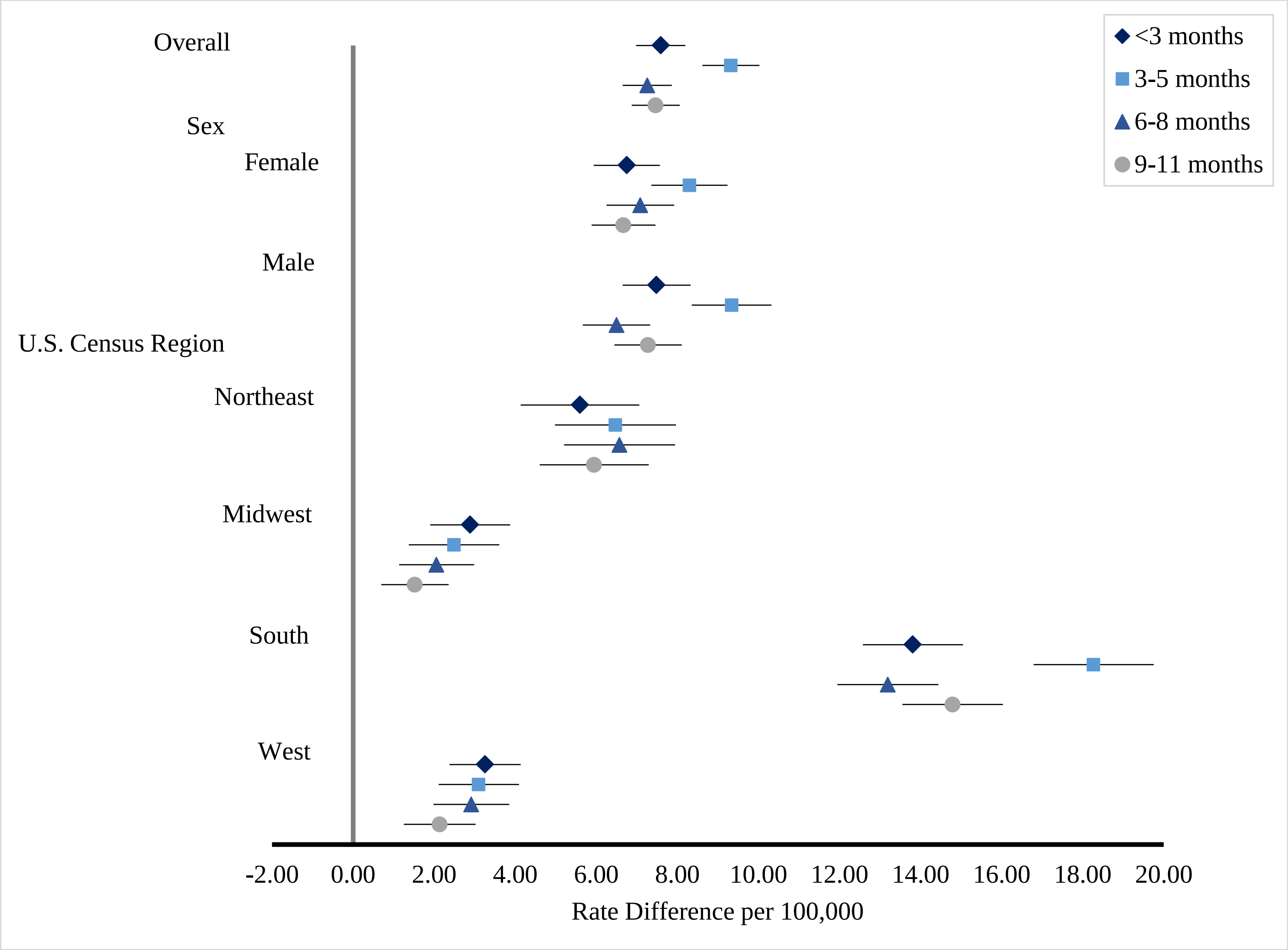


Figure 3-7a. Rate ratios and 95% confidence intervals comparing extended summer and winter incidence of nontyphoidal salmonellosis by age group, sex, and U.S. Census region, 2010–2015

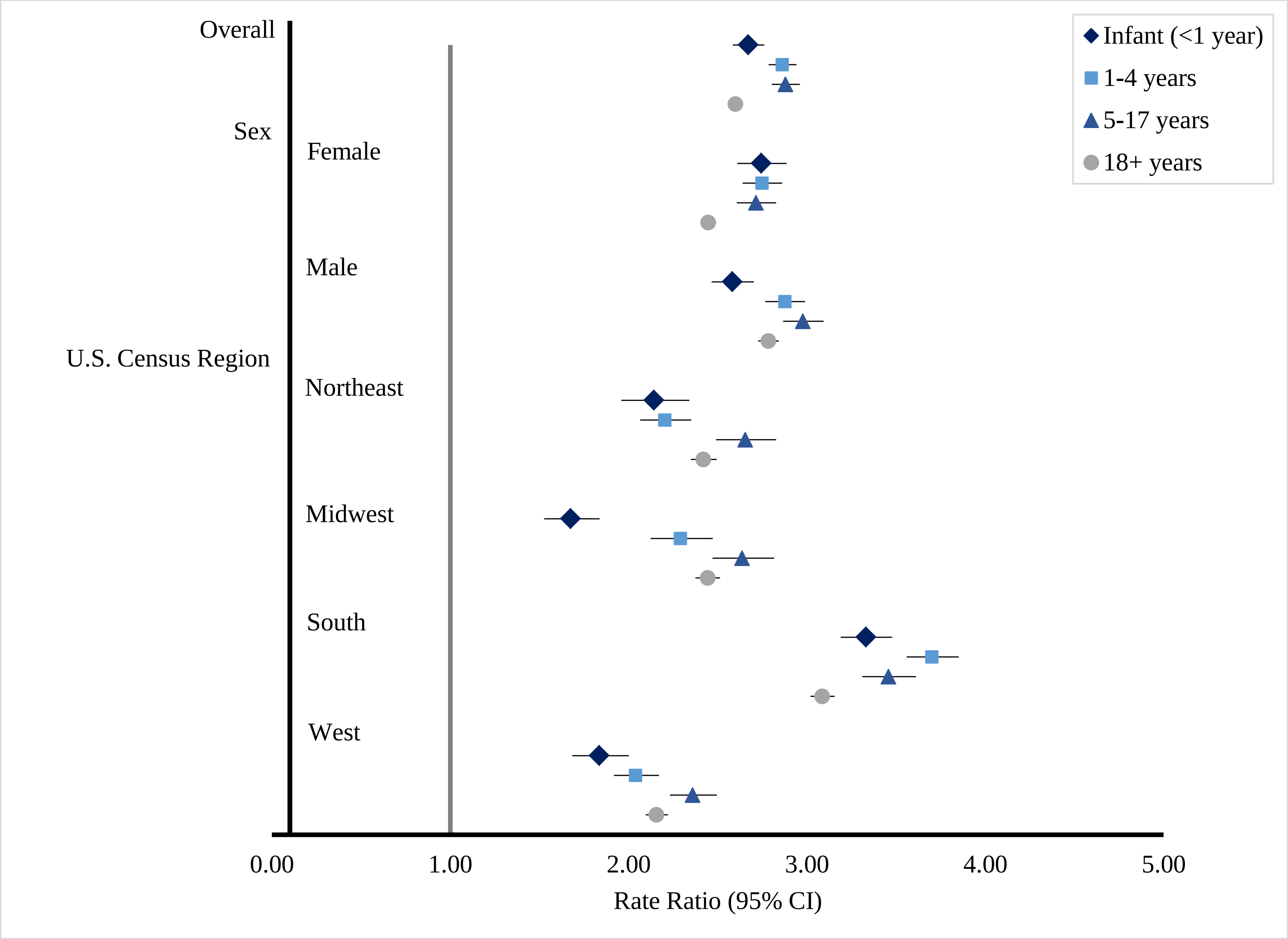
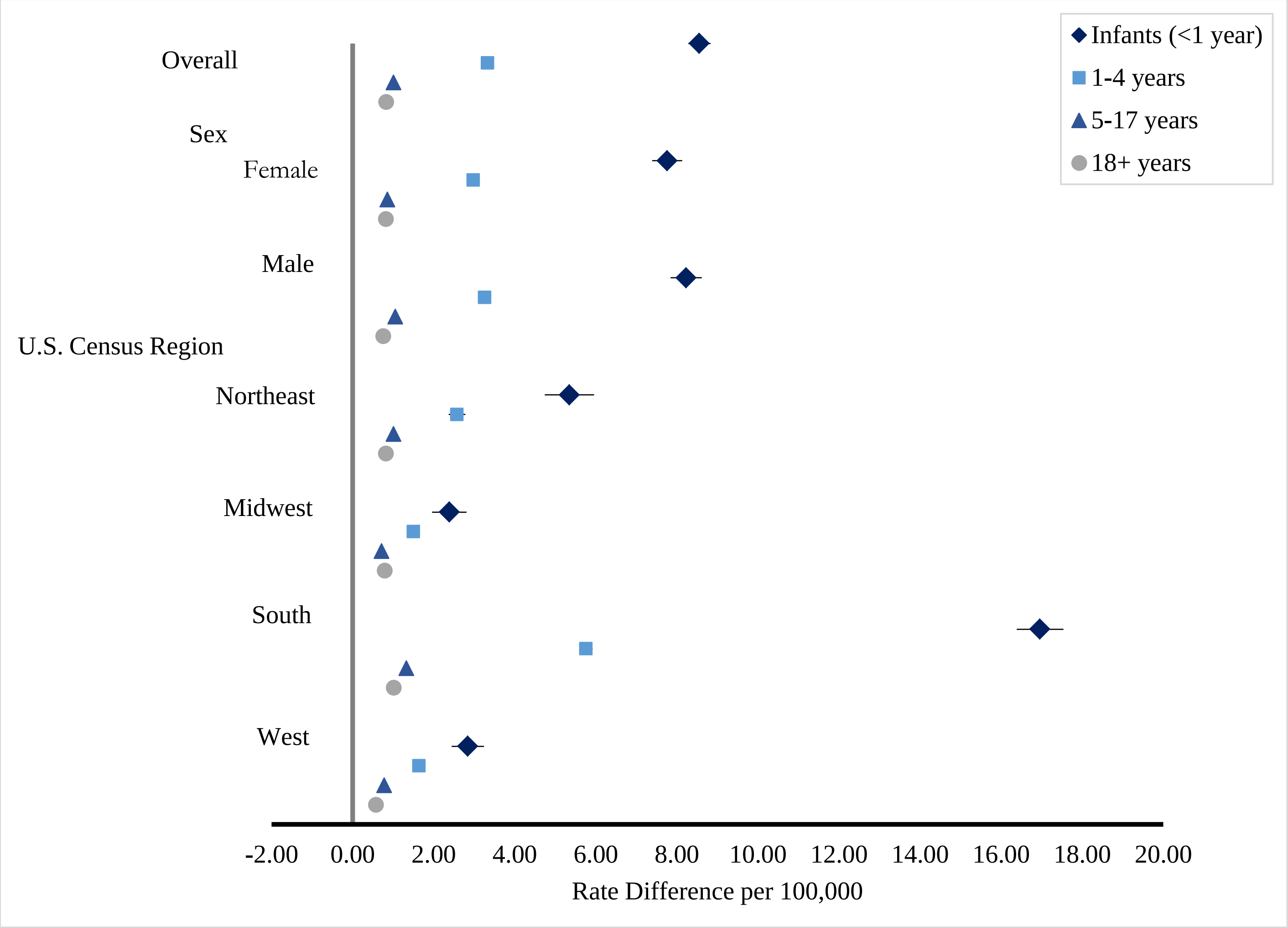


Figure 3-7b. Rate differences and 95% confidence intervals comparing extended summer and winter incidence of nontyphoidal salmonellosis by age group, sex, and U.S. Census region, 2010–2015



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CONCLUSION

With this dissertation, we set out to explore the relationship between environmental heat and select child health outcomes in the United States. The first study, overall,found little to no short-term association between maternal heat wave exposure and preterm birth in Massachusetts, using five definitions of heat wave. However, stratified analyses revealed potential increases in risk at earlier gestational ages and at less extreme levels of heat, which should be explored in future studies. Findings from the second study provided some evidence for increased rates of emergency department (ED) visits for asthma among Massachusetts children during and immediately following heat waves, although excess numbers were small. Additionally, slightly elevated rates for all-cause pediatric ED visits during heat waves corresponded to hundreds and even thousands of excess visits when lag days were considered. Finally, the third study confirmed elevated rates of salmonellosis in the summer compared to winter among infants in the U.S. and revealed a greater absolute impact compared to other age groups, especially among infants in the South and for serotypes commonly from environmental, non-food sources.

These studies contribute to the broader effort by public health scientists to establish baseline relationships between weather factors, in this case environmental heat, and child health outcomes (McMichael et al. 2003). It is important to examine such relationships at a regional level, as an observed association between weather and health outcomes in a population is considered a key indicator of vulnerability to future impacts of climate change (Patz et al. 2014). Additionally, exposure, background rates of disease, and mediating factors (e.g., population characteristics, adaptive capacity) affect vulnerability and may vary by geographic area (WHO 2002; McMichael et al. 2003; Smith et al. 2014; Ebi et al. 2018). Notably, these factors may also change over time (McMichael et al. 2003). Public health surveillance systems need to be in place and select indicators tracked to detect differences in incidence of climate-sensitive health outcomes by geography and over time in order to initiate targeted, appropriate responses (McMichael et al. 2003; Frumkin et al. 2008; Sheffield and Landrigan 2011).

Enhancing efforts that address current public health issues, especially those that are climate-sensitive, may prove most effective in the near term to reduce vulnerability to climate change (Smith et al. 2014; Ebi et al. 2009). This is because, according to the Intergovernmental Panel on Climate Change (IPCC), over the next few decades climate change will primarily act by exacerbating existing health problems. In fact, the IPCC maintains that the background rate of climate-sensitive health outcomes in a population is often the best measure of vulnerability, as the absolute impact would be greater when the background rate is high (Smith et al. 2014). If we apply this line of reasoning to Study 3 of this dissertation, findings suggest that infants, especially those in the South, may be disproportionately impacted by future increases in ambient temperature as they had greater salmonellosis rate differences compared to other age groups, despite similar rate ratios.

Both mitigation and adaptation strategies are necessary to limit the health impacts of climate change (Xu et al. 2012; Ebi et al. 2018). Because the extent of projected warming beyond mid-century largely depends on emission scenarios, emissions mitigation is essential (Ebi et al. 2018). Analagous to primary prevention in public health, mitigation aims to reduce greenhouse gas emissions thereby limiting the extent of future warming (Frumkin et al. 2008; Ebi et al. 2018). This has important implications for health toward the end of the century. Achieving a lower emissions scenario (RCP4.5), where global carbon emissions begin decreasing by 2050, would reduce by half the negative impact on health outcomes and related costs annually in the U.S. compared to a high emissions scenario (RCP8.5) in which emissions continue to increase (Ebi et al. 2018). This equates to savings of thousands of lives and hundreds of billions of dollars in the U.S. alone by the end of the century (Ebi et al. 2018).

However, because temperatures are projected to rise regardless of emission scenario, developing adaptive strategies, akin to secondary and tertiary prevention, is also critical (McMichael et al. 2003; Frumkin et al. 2008; Dahl et al. 2019). Children should be explicitly considered in such strategies (USEPA 2014; Ebi et al. 2018). Not only are they inherently susceptible to climate-sensitive health effects by virtue of age-related biological and behavioral factors, but because they are young, the number of years potentially impacted by climate-related morbidity is great (Sheffield and Landrigan 2011). For instance, Studies 1 and 2 of this dissertation focused on Massachusetts, which passed the Global Warming Solutions Act of 2008 forming the Climate Change Adaptation Advisory Committee. A 2011 Committee report described strategies to make the state’s environment, infrastructure and communities more resilient to climate change and highlighted young people as a vulnerable subpopulation warranting further risk assessment (MA Adaptation Report 2011). Worth noting, children in less developed areas of the world as well as those in lower-income communities in developed countries, like the U.S., are especially vulnerable, and while we were limited in our ability to assess socioeconomic status in our studies, this disparity should be considered in future research and prevention efforts (McMichael et al. 2003; Xu et al. 2012; Ebi et al. 2018).

In closing, findings from this dissertation should not be viewed in isolation, but rather as part of a growing body of scientific literature on the potential impacts of climate change on child health. This work provides evidence that environmental heat is associated with certain adverse health outcomes among children in the United States and raises questions for further research. Findings could be used as a baseline and compared with future estimates to assess changes in vulnerability and inform public health interventions.

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APPENDIX 1A.

Method used to calculate Heat Index (HI) based on the National Weather Service (NWS) formula –Laurie Agel and Mathew Barlow, UMass Lowell

Briefly, the NWS formula for heat index (HI) in the figure below is based on temperature (T) and relative humidity (RH). It sets HI equal to ambient temperatures at or below 40 ºF, uses a simple calculation for ambient temperatures of 40–79 ºF, and uses a more complicated calculation for ambient temperatures on or above 80 ºF — with additional adjustments when temperatures are 80–112 ºF and RH <= 13%, or when temperatures are 80–87 ºF and RH >85%.

HI is normally calculated using simultaneous measures of T and RH (e.g. hourly observations, or time of maximum/minimum temperature). RH is the ratio of vapor pressure (e) to saturated vapor pressure (es), where RH and es are calculated as in Eq. 1. However, there is limited availability of instantaneous T and RH for the target cities for the time period considered. To overcome this limitation, we use a long-running high-resolution gridded dataset of surface conditions (“daymet”) from the United State Coast Guard (USGS) data portal, located at https://cida.usgs.gov/gdp, which provides daily maximum temperature (Tmax), daily minimum temperature (Tmin), and daily mean specific vapor pressure at ~1 km resolution. We calculate a variant of RH, called here RHavg, which uses the mean of Tmin and Tmax instead of T in the calculation of es, and the mean vapor pressure for e in the calculation for RH.

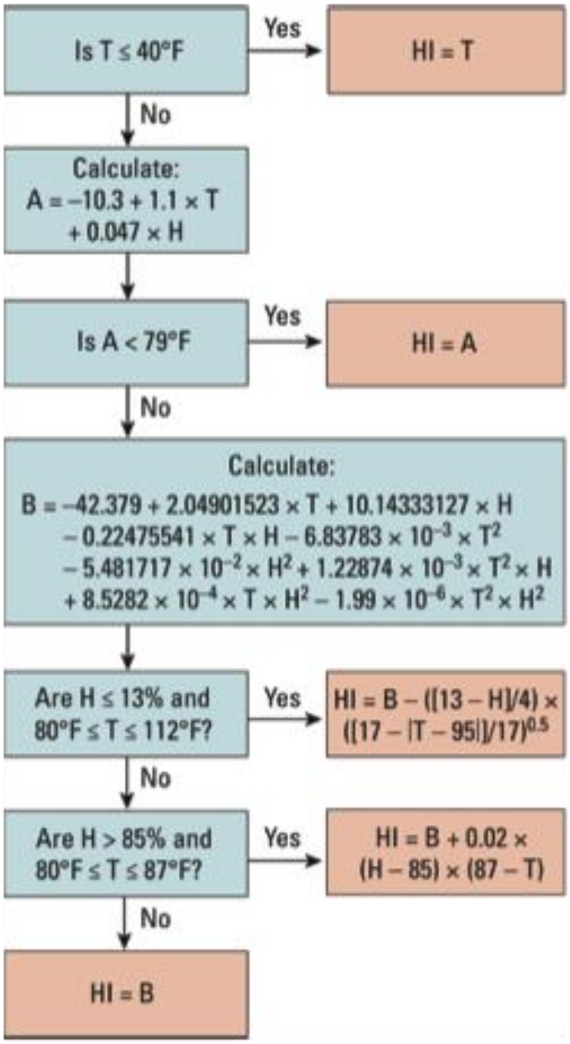
The maximum heat index HImax can then be calculated using Tmax and RHavg. However, this results in instances where HImax is slightly lower than Tmax, which is

APPENDIX 1A (CONT).

nonsensical. This occurs occasionally when Tmax is below 70ºF, especially in April and October, and extremely rarely at temperatures above 70ºF. Therefore we modify the NWS algorithm to adjust HImax to Tmax if HImax is less than Tmax.

RH = e /es, where

es = 0.6112*exp(17.67*T/(T+243.5)), where T is in ºC, and es is in kPa Eq. (1)



APPENDIX 1B.

Percent and Number of births occurring during May–September,
10 Massachusetts cities, 1993–2010

	Total number of births	Percent (number) May–September
All births	404,655	43.2 (174,772)
Pre-term	36,723	42.1 (15,472)
Singleton pre-term	29,237	42.4 (12,382)

APPENDIX 1C.

Calculating odds ratios (OR) of the effect of heatwave exposure on preterm birth using discordant pairs analysis, ten Massachusetts cities, 1993–2010 (n=12,382 preterm births)

		Risk		
		E+	E-	Total
Reference	E+	A	**B**	E+ref
	E-	**C**	D	E-ref
	Total	E+risk	E-risk	# pairs

where

A= # pairs where e_risk=1 and e_ref=1 (Concordant)
B= # pairs where e_risk=0 and e_ref=1 (Discordant)
C= # pairs where e_risk=1 and e_ref=0 (Discordant)
D= # pairs where e_risk=0 and e_ref=0 (Concordant)

OR = C/B

HW1 (85th percentile)

		Risk			
		E+	E-	TOTAL	OR=
Reference	E+	5507	**7166**	12673	**1.05**
	E-	**7493**	29362	36855	
	Total	13000	36528	49528 pairs	

HW2 (90th percentile)

		Risk			
		E+	E-	TOTAL	OR=
Reference	E+	2921	**5851**	8772	**1.03**
	E-	**6031**	34725	40756	
	Total	8952	40576	49528 pairs	

HW3 (95th percentile)

		Risk			
		E+	E-	TOTAL	OR=
Reference	E+	892	**3562**	4454	**1.01**
	E-	**3612**	41462	45074	
	Total	4504	45024	49528 pairs	

HW4 (98th percentile)

		Risk			
		E+	E-	TOTAL	OR=
Reference	E+	129	**1743**	1872	**0.96**
	E-	**1667**	45989	47656	
	Total	1796	47732	49528 pairs	

HW5 (90°F)

		Risk			
		E+	E-	TOTAL	
Reference	E+	117	**1698**	1815	OR=
	E-	**1683**	46030	47713	**0.99**
	Total	1800	47728	49528 pairs	

APPENDIX 1D.

Odds ratios (OR) and 95% confidence intervals (CI) for the short-term effect of heat wave exposure (HW1-5) on preterm birth from conditional logistic regression models

		HW1				HW2			
	N[1]	% exposed[2]	OR	95% CI		% exposed	OR	95% CI	
Overall	12382	26.3	1.05	0.99	1.10	18.1	1.03	0.97	1.09
By Gestational Age									
Early Preterm (20–27 weeks)	1014	26.8	1.13	0.95	1.35	18.1	1.06	0.88	1.29
Moderately Preterm (28–33 weeks)	2735	26.1	1.07	0.96	1.19	18.0	1.07	0.95	1.21
Late Preterm (34–36 weeks)	8633	26.2	1.03	0.97	1.09	18.1	1.01	0.95	1.08
By Delivery Month									
May/June	5037	13.2	1.03	0.94	1.14	8.6	1.02	0.91	1.15
Jul/Aug/Sept	7345	35.2	1.05	0.99	1.11	24.6	1.03	0.97	1.10
By Maternal Age									
<20	1704	26.1	1.01	0.88	1.16	18.1	1.05	0.91	1.22
20–29	5814	25.6	1.00	0.93	1.08	17.7	1.01	0.93	1.09
30–39	4435	27.4	1.14	1.05	1.24	18.7	1.06	0.97	1.17
40–54	429	23.8	0.91	0.69	1.20	17.0	0.95	0.70	1.28
By Maternal Race/Ethnicity									
Hispanic	3349	26.6	1.05	0.95	1.16	18.6	1.05	0.95	1.17
White, non-Hispanic	4318	25.1	1.03	0.95	1.12	17.4	1.03	0.94	1.13
Black, non-Hispanic	3339	27.1	1.07	0.97	1.18	18.1	1.00	0.90	1.11
Other, non-Hispanic	1329	27.0	1.01	0.87	1.18	19.3	1.05	0.89	1.24

[1] Number of risk periods (i.e. preterm births)

[2] Percent of risk periods exposed to heat wave

APPENDIX 1D (CONT).

	HW3				HW4				HW5			
	% exposed[2]	OR	95% CI		% exposed	OR	95% CI		% exposed	OR	95% CI	
Overall	9.1	1.01	0.94	1.09	3.6	0.96	0.86	1.06	3.6	0.99	0.89	1.10
By Gestational Age												
Early Preterm (20–27 weeks)	8.9	1.04	0.80	1.34	3.4	0.94	0.64	1.37	3.4	0.90	0.62	1.32
Moderately Preterm (28–33 weeks)	9.6	1.11	0.95	1.29	3.6	0.92	0.73	1.15	3.9	1.07	0.86	1.34
Late Preterm (34–36 weeks)	9.0	0.98	0.90	1.07	3.7	0.97	0.86	1.10	3.6	0.98	0.86	1.11
By Delivery Month												
May/June	3.7	0.92	0.78	1.09	1.0	0.63	0.47	0.85	1.3	0.74	0.57	0.96
Jul/Aug/Sept	12.8	1.04	0.96	1.13	5.4	1.03	0.92	1.15	5.2	1.06	0.94	1.19
By Maternal Age												
<20	8.7	1.11	0.91	1.36	3.4	1.01	0.75	1.37	3.8	1.03	0.77	1.36
20–29	9.1	0.98	0.89	1.09	3.5	0.89	0.76	1.04	3.4	0.89	0.76	1.04
30–39	9.3	1.02	0.91	1.16	4.0	1.05	0.89	1.25	4.0	1.15	0.97	1.37
40–54	8.9	0.97	0.66	1.43	2.8	0.68	0.36	1.28	3.0	0.75	0.41	1.39
By Maternal Race/Ethnicity												
Hispanic	10.1	1.16	1.02	1.33	3.8	0.98	0.81	1.20	4.1	0.98	0.80	1.19
White, non-Hispanic	8.6	0.99	0.88	1.12	3.4	1.00	0.83	1.21	3.5	1.15	0.95	1.38
Black, non-Hispanic	8.7	0.93	0.81	1.07	3.8	0.92	0.75	1.12	3.4	0.85	0.69	1.05
Other, non-Hispanic	9.4	0.95	0.77	1.19	3.5	0.88	0.63	1.23	3.4	0.97	0.70	1.36

[2] Percent of risk periods exposed to heat wave

APPENDIX 2A.

Dates of T90 heat waves (HW) defined as ≥ 3 days with maximum ambient temperature ≥ 90˚F and reference (REF) periods, by Massachusetts city, ten-cities analysis, 2005–2014

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Boston	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	3	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	4	6/8/2008	6/10/2008	6/1/2008	6/3/2008	3
	5	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	6	7/5/2010	7/7/2010	6/21/2010	6/23/2010	3
	7	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	8	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	9	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
	10	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Brockton	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	3	8/2/2007	8/4/2007	7/26/2007	7/28/2007	3
	4	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	5	7/18/2008	7/20/2008	7/11/2008	7/13/2008	3
	6	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	7	7/5/2010	7/8/2010	6/21/2010	6/24/2010	4
	8	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	9	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	10	7/15/2012	7/18/2012	7/8/2012	7/11/2012	4
	11	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	12	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
	13	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Cambridge	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	3	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	4	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	5	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	6	7/5/2010	7/7/2010	7/19/2010	7/21/2010	3
	7	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	8	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	9	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	10	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
	11	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6

APPENDIX 2A (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Lawrence	1	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	2	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	3	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	4	8/16/2009	8/19/2009	8/9/2009	8/12/2009	4
	5	7/5/2010	7/9/2010	7/19/2010	7/23/2010	5
	6	8/30/2010	9/3/2010	8/16/2010	8/20/2010	5
	7	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	8	7/13/2012	7/18/2012	7/27/2012	8/1/2012	6
	9	5/31/2013	6/2/2013	5/24/2013	5/26/2013	3
	10	7/16/2013	7/20/2013	7/30/2013	8/3/2013	5
Lowell	1	6/25/2005	6/27/2005	6/18/2005	6/20/2005	3
	2	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	3	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	4	8/16/2009	8/20/2009	8/2/2009	8/6/2009	5
	5	7/5/2010	7/10/2010	7/19/2010	7/24/2010	6
	6	8/30/2010	9/3/2010	8/16/2010	8/20/2010	5
	7	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	8	6/21/2012	6/23/2012	6/14/2012	6/16/2012	3
	9	7/13/2012	7/18/2012	7/27/2012	8/1/2012	6
	10	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
	11	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Lynn	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	3	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	4	7/5/2010	7/7/2010	7/19/2010	7/21/2010	3
	5	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	6	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	7	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
New Bedford	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	7/18/2008	7/20/2008	7/11/2008	7/13/2008	3
	3	7/5/2010	7/7/2010	6/28/2010	6/30/2010	3
	4	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	5	7/18/2013	7/20/2013	8/1/2013	8/3/2013	3

APPENDIX 2A (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Quincy	1	8/1/2006	8/3/2006	7/25/2006	7/27/2006	3
	2	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	3	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	4	6/8/2008	6/10/2008	6/1/2008	6/3/2008	3
	5	7/18/2008	7/20/2008	7/11/2008	7/13/2008	3
	6	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	7	7/5/2010	7/7/2010	7/19/2010	7/21/2010	3
	8	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	9	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	10	7/5/2013	7/7/2013	6/28/2013	6/30/2013	3
	11	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Springfield	1	8/3/2005	8/5/2005	7/20/2005	7/22/2005	3
	2	8/11/2005	8/14/2005	8/25/2005	8/28/2005	4
	3	7/17/2006	7/19/2006	7/10/2006	7/12/2006	3
	4	8/1/2006	8/4/2006	7/25/2006	7/28/2006	4
	5	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	6	7/19/2008	7/21/2008	7/12/2008	7/14/2008	3
	7	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	8	7/5/2010	7/9/2010	6/21/2010	6/25/2010	5
	9	8/30/2010	9/3/2010	8/16/2010	8/20/2010	5
	10	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	11	7/17/2012	7/19/2012	7/10/2012	7/12/2012	3
	12	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	13	7/5/2013	7/8/2013	6/28/2013	7/1/2013	4
	14	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Worcester	1	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	2	7/18/2013	7/20/2013	7/11/2013	7/13/2013	3

APPENDIX 2B.

Dates of P95 heat waves (HW) defined as ≥ 2 days with maximum heat index > 95th percentile of warm season heat index and reference (REF) periods by Massachusetts city, ten-cities analysis, 2005–2014

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Boston	1	7/19/2005	7/20/2005	7/12/2005	7/13/2005	2
	2	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	3	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	4	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	5	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	6	8/3/2007	8/4/2007	7/20/2007	7/21/2007	2
	7	6/9/2008	6/10/2008	6/2/2008	6/3/2008	2
	8	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	9	7/6/2010	7/7/2010	6/29/2010	6/30/2010	2
	10	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	11	8/4/2010	8/5/2010	8/18/2010	8/19/2010	2
	12	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3
	13	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	14	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	15	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	16	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	17	5/31/2013	6/1/2013	5/24/2013	5/25/2013	2
	18	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	19	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	20	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2
Brockton	1	7/19/2005	7/20/2005	7/12/2005	7/13/2005	2
	2	7/26/2005	7/27/2005	8/9/2005	8/10/2005	2
	3	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	4	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	7	8/2/2007	8/4/2007	7/26/2007	7/28/2007	3
	8	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	9	7/19/2008	7/20/2008	7/12/2008	7/13/2008	2
	10	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	11	6/28/2010	6/29/2010	7/12/2010	7/13/2010	2
	12	7/5/2010	7/8/2010	6/21/2010	6/24/2010	4
	13	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	14	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3

APPENDIX 2B (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Brockton (cont.)	15	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	16	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	17	7/15/2012	7/18/2012	7/8/2012	7/11/2012	4
	18	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	19	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	20	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Cambridge	1	7/19/2005	7/20/2005	7/12/2005	7/13/2005	2
	2	7/26/2005	7/27/2005	8/9/2005	8/10/2005	2
	3	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	4	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	7	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	8	6/8/2008	6/10/2008	6/1/2008	6/3/2008	3
	9	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	10	7/6/2010	7/7/2010	6/29/2010	6/30/2010	2
	11	8/4/2010	8/5/2010	7/28/2010	7/29/2010	2
	12	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3
	13	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	14	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	15	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	16	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	17	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	18	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	19	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2
Lawrence	1	7/19/2005	7/20/2005	7/12/2005	7/13/2005	2
	2	7/26/2005	7/27/2005	8/9/2005	8/10/2005	2
	3	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	4	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	5	7/27/2006	7/28/2006	7/13/2006	7/14/2006	2
	6	8/2/2006	8/3/2006	8/16/2006	8/17/2006	2
	7	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	8	8/3/2007	8/4/2007	7/20/2007	7/21/2007	2
	9	8/25/2007	8/26/2007	8/18/2007	8/19/2007	2
	10	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	11	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	12	7/6/2010	7/10/2010	6/22/2010	6/26/2010	5

APPENDIX 2B (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Lawrence (cont.)	13	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	14	8/31/2010	9/3/2010	8/24/2010	8/27/2010	4
	15	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	16	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	17	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	18	8/4/2012	8/5/2012	7/28/2012	7/29/2012	2
	19	6/1/2013	6/2/2013	5/25/2013	5/26/2013	2
	20	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	21	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	22	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2
Lowell	1	6/26/2005	6/27/2005	6/19/2005	6/20/2005	2
	2	7/19/2005	7/20/2005	7/12/2005	7/13/2005	2
	3	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	4	8/2/2006	8/3/2006	8/16/2006	8/17/2006	2
	5	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	6	8/3/2007	8/4/2007	7/20/2007	7/21/2007	2
	7	8/25/2007	8/26/2007	8/18/2007	8/19/2007	2
	8	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	9	8/17/2009	8/20/2009	8/10/2009	8/13/2009	4
	10	7/6/2010	7/10/2010	6/22/2010	6/26/2010	5
	11	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	12	8/31/2010	9/3/2010	8/24/2010	8/27/2010	4
	13	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	14	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	15	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	16	8/4/2012	8/5/2012	7/28/2012	7/29/2012	2
	17	6/1/2013	6/2/2013	5/25/2013	5/26/2013	2
	18	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	19	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	20	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2
Lynn	1	7/26/2005	7/27/2005	7/12/2005	7/13/2005	2
	2	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	3	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	4	7/28/2006	7/29/2006	7/14/2006	7/15/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	7	8/3/2007	8/4/2007	7/20/2007	7/21/2007	2

APPENDIX 2B (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Lynn (cont.)	8	8/25/2007	8/26/2007	8/18/2007	8/19/2007	2
	9	6/9/2008	6/10/2008	6/2/2008	6/3/2008	2
	10	7/19/2008	7/20/2008	7/12/2008	7/13/2008	2
	11	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	12	7/5/2010	7/7/2010	6/28/2010	6/30/2010	3
	13	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	14	8/4/2010	8/5/2010	8/18/2010	8/19/2010	2
	15	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3
	16	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	17	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	18	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	19	6/1/2013	6/2/2013	5/25/2013	5/26/2013	2
	20	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	21	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	22	7/1/2014	7/3/2014	6/24/2014	6/26/2014	3
	23	7/8/2014	7/9/2014	7/22/2014	7/23/2014	2
New Bedford	1	7/20/2005	7/21/2005	7/13/2005	7/14/2005	2
	2	8/11/2005	8/14/2005	7/28/2005	7/31/2005	4
	3	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	4	7/29/2006	7/30/2006	7/22/2006	7/23/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	8/2/2007	8/4/2007	7/26/2007	7/28/2007	3
	7	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	8	7/18/2008	7/21/2008	7/11/2008	7/14/2008	4
	9	8/18/2009	8/20/2009	8/4/2009	8/6/2009	3
	10	6/28/2010	6/29/2010	7/12/2010	7/13/2010	2
	11	7/5/2010	7/8/2010	6/21/2010	6/24/2010	4
	12	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	13	8/30/2010	9/2/2010	8/23/2010	8/26/2010	4
	14	7/22/2011	7/23/2011	7/15/2011	7/16/2011	2
	15	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	16	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	17	8/4/2012	8/5/2012	7/28/2012	7/29/2012	2
	18	6/25/2013	6/26/2013	6/18/2013	6/19/2013	2
	19	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Qunicy	1	7/19/2005	7/20/2005	7/5/2005	7/6/2005	2
	2	7/26/2005	7/27/2005	7/12/2005	7/13/2005	2

APPENDIX 2B (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Quincy (cont.)	3	8/13/2005	8/14/2005	8/6/2005	8/7/2005	2
	4	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	6/26/2007	6/28/2007	6/19/2007	6/21/2007	3
	7	8/2/2007	8/4/2007	7/19/2007	7/21/2007	3
	8	6/9/2008	6/10/2008	6/2/2008	6/3/2008	2
	9	7/19/2008	7/20/2008	7/12/2008	7/13/2008	2
	10	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	11	6/28/2010	6/29/2010	7/12/2010	7/13/2010	2
	12	7/6/2010	7/7/2010	6/22/2010	6/23/2010	2
	13	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	14	8/4/2010	8/5/2010	8/18/2010	8/19/2010	2
	15	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3
	16	7/21/2011	7/23/2011	7/14/2011	7/16/2011	3
	17	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	18	7/14/2012	7/18/2012	7/7/2012	7/11/2012	5
	19	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	20	5/31/2013	6/1/2013	5/24/2013	5/25/2013	2
	21	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	22	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
	23	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2
Springfield	1	6/26/2005	6/27/2005	6/19/2005	6/20/2005	2
	2	8/4/2005	8/5/2005	7/21/2005	7/22/2005	2
	3	8/12/2005	8/14/2005	7/29/2005	7/31/2005	3
	4	7/17/2006	7/19/2006	7/10/2006	7/12/2006	3
	5	8/2/2006	8/4/2006	7/26/2006	7/28/2006	3
	6	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	7	7/10/2007	7/11/2007	7/24/2007	7/25/2007	2
	8	8/3/2007	8/4/2007	7/27/2007	7/28/2007	2
	9	6/9/2008	6/11/2008	6/2/2008	6/4/2008	3
	10	7/19/2008	7/21/2008	7/12/2008	7/14/2008	3
	11	8/17/2009	8/19/2009	8/10/2009	8/12/2009	3
	12	7/6/2010	7/9/2010	6/22/2010	6/25/2010	4
	13	7/17/2010	7/18/2010	7/31/2010	8/1/2010	2
	14	9/1/2010	9/3/2010	8/25/2010	8/27/2010	3
	15	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	16	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2

APPENDIX 2B (CONT.)

City	HW#	HW start	HW end	REF start	REF end	Duration (days)
Springfield (cont.)	17	7/17/2012	7/19/2012	7/10/2012	7/12/2012	3
	18	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	19	6/24/2013	6/25/2013	6/17/2013	6/18/2013	2
	20	7/15/2013	7/20/2013	7/29/2013	8/3/2013	6
Worcester	1	6/12/2005	6/13/2005	6/5/2005	6/6/2005	2
	2	6/26/2005	6/27/2005	6/19/2005	6/20/2005	2
	3	8/11/2005	8/14/2005	7/28/2005	7/31/2005	4
	4	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
	5	8/1/2006	8/3/2006	8/15/2006	8/17/2006	3
	6	6/27/2007	6/28/2007	6/20/2007	6/21/2007	2
	7	6/8/2008	6/11/2008	6/1/2008	6/4/2008	4
	8	7/18/2008	7/20/2008	7/11/2008	7/13/2008	3
	9	8/16/2009	8/19/2009	8/9/2009	8/12/2009	4
	10	7/5/2010	7/9/2010	7/19/2010	7/23/2010	5
	11	8/31/2010	9/2/2010	8/24/2010	8/26/2010	3
	12	7/21/2011	7/24/2011	7/14/2011	7/17/2011	4
	13	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
	14	7/16/2012	7/18/2012	7/9/2012	7/11/2012	3
	15	8/3/2012	8/5/2012	7/27/2012	7/29/2012	3
	16	7/16/2013	7/20/2013	7/30/2013	8/3/2013	5
	17	7/2/2014	7/3/2014	6/25/2014	6/26/2014	2

APPENDIX 2C.

P95 heat waves (HW) defined as ≥ 2 days with maximum heat index > 95th percentile of warm season heat index and reference (REF) periods for statewide analysis, Massachusetts, 2005–2014

HW#	HW start	HW end	REF start	REF end	Duration (days)
1	7/17/2006	7/18/2006	7/10/2006	7/11/2006	2
2	8/2/2006	8/3/2006	8/16/2006	8/17/2006	2
3	6/9/2008	6/10/2008	6/2/2008	6/3/2008	2
4	8/18/2009	8/19/2009	8/4/2009	8/5/2009	2
5	9/1/2010	9/2/2010	8/25/2010	8/26/2010	2
6	7/22/2011	7/23/2011	7/15/2011	7/16/2011	2
7	6/21/2012	6/22/2012	6/14/2012	6/15/2012	2
8	7/17/2012	7/18/2012	7/10/2012	7/11/2012	2
9	7/16/2013	7/20/2013	7/30/2013	8/3/2013	5

APPENDIX 2D.

Dates of lag days in the statewide analysis that met criteria for a heat wave day, Massachusetts, 2005–2014

Lag day type	Date	Lag day number	City
Heat wave	7/19/2006	1	Springfield
	6/11/2008	1	Brockton, Lawrence, Lowell, New Bedford, Springfield, Worcester
	8/20/2009	1	Lowell, New Bedford
	8/21/2009	2	Springfield
	8/22/2009	3	Brockton, Lawrence, Lowell
	9/30/2010	1	Springfield, Lowell, Lawrence
	7/24/2011	1	Lawrence, Lowell, Springfield, Worcester
	7/19/2012	1	Springfield
Reference	7/14/2012	3	Boston, Cambridge, Lawrence, Lowell, Lynn, New Bedford, Quincy

APPENDIX 3A.

Methods to obtain population estimates for rate denominators.

Two U.S. Census data files were used to derive population estimates for rate denominators. The first file, “Vintage 2016 Population Estimates: National Monthly Population Estimates”, contained population estimates by individual year of age, month and sex for April 2010 through December 2015 (US Census 2016a). Monthly estimates were summed across six years by age group and sex. However, because population estimates for January, February, and March 2010 were not available in the original file, these were approximated. The percentages of the total annual populations in each of the three months for the years 2011, 2012 and 2013 were calculated. Because they were similar, they were combined and averaged (~25%). The April–December 2010 population estimate was then divided by 75% to get the new 12-month total for 2010. Individual monthly percentages were applied to this new total to get monthly estimates for January, February and March 2010. These monthly totals were added to the corresponding five-year monthly sums to obtain six-year monthly estimates for each of the three months. Population estimates for each season were calculated by summing corresponding three monthly estimates across the six years by age group and sex. For instance, summer was the sum of June, July, August estimates, and winter was the sum of December, January and February estimates.

In a separate file, “Vintage 2016 Population Estimates: Characteristics by Single Year of Age”, annual estimates for 2010–2015 by individual year of age, sex, and state were available (US Census 2016b). States were grouped into four U.S. Census regions and nine divisions (Figure 2). A dataset was created with population estimates and percentages for U.S. Census regions and divisions by year, age group, and sex. Then, to estimate monthly and seasonal estimates for each region (or division) by age group, sex, and year, the percentages were multiplied by the corresponding monthly or seasonal totals from the first dataset. They were then combined across years for each region. The assumption with this approach was that, in each respective stratum, the population percent by region did not change by season. This was likely reasonable for all age groups except older adults who might be more likely to travel south in winter. Lastly, for population estimates for the secondary analysis of four infant age groups, the stratum specific totals for all infants were divided by four.

APPENDIX 3B.

Comparison of incidence rates of nontyphoidal salmonellosis by season, age group, sex, and geography, U.S., 2010–2015.

	Infants (< 1 year)											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	9315	71118861	13.10	3697	71275500	5.19	2.53	2.43	2.62	7.91	7.60	8.23
Sex												
Female	4075	34752378	11.73	1575	34828276	4.52	2.59	2.45	2.75	7.20	6.78	7.63
Male	4680	36366483	12.87	1901	36447225	5.22	2.47	2.34	2.60	7.65	7.22	8.09
Census Region												
Northeast (1)	1211	11448095	10.58	508	11473309	4.43	2.39	2.15	2.65	6.15	5.44	6.86
Midwest (2)	856	14991366	5.71	521	15024384	3.47	1.65	1.48	1.84	2.24	1.76	2.73
South (3)	6152	27221676	22.60	2068	27281631	7.58	2.98	2.84	3.13	15.02	14.37	15.67
West (4)	1096	17457724	6.28	599	17496175	3.42	1.83	1.66	2.03	2.85	2.39	3.32
Census Division												
New England (1)	204	2734104	7.46	86	2740126	3.14	2.38	1.85	3.06	4.32	3.10	5.54
Middle Atlantic (2)	1007	8713991	11.56	422	8733183	4.83	2.39	2.13	2.68	6.72	5.87	7.57
East North Central (3)	478	10106520	4.73	317	10128780	3.13	1.51	1.31	1.74	1.60	1.05	2.15
West North Central (4)	378	4884846	7.74	204	4895604	4.17	1.86	1.57	2.20	3.57	2.60	4.54
South Atlantic (5)	2785	13300925	20.94	897	13330220	6.73	3.11	2.89	3.35	14.21	13.32	15.10
East South Central (6)	1024	4182513	24.48	292	4191724	6.97	3.51	3.09	4.00	17.52	15.82	19.22
West South Central (7)	2343	9738238	24.06	879	9759687	9.01	2.67	2.47	2.89	15.05	13.91	16.20
Mountain (8)	390	5543724	7.03	272	5555934	4.90	1.44	1.23	1.68	2.14	1.23	3.05
Pacific (9)	706	11914000	5.93	327	11940240	2.74	2.16	1.90	2.47	3.19	2.66	3.72

APPENDIX 3B (CONT.)

	Age 1–4 years											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	14659	288738075	5.08	5164	289278573	1.79	2.84	2.76	2.94	3.29	3.20	3.39
Sex												
Female	6601	141222780	4.67	2430	141495537	1.72	2.72	2.60	2.85	2.96	2.82	3.09
Male	7270	147515295	4.93	2540	147783036	1.72	2.87	2.74	3.00	3.21	3.08	3.34
Census Region												
Northeast (1)	2260	46228587	4.89	947	46315124	2.04	2.39	2.22	2.58	2.84	2.60	3.08
Midwest (2)	1673	61235361	2.73	699	61349989	1.14	2.40	2.20	2.62	1.59	1.44	1.75
South (3)	8432	110347029	7.64	2422	110553591	2.19	3.49	3.33	3.65	5.45	5.27	5.64
West (4)	2294	70927098	3.23	1096	71059869	1.54	2.10	1.95	2.25	1.69	1.53	1.85
Census Division												
New England (1)	424	11281680	3.76	188	11302798	1.66	2.26	1.90	2.68	2.10	1.67	2.52
Middle Atlantic (2)	1836	34946907	5.25	759	35012325	2.17	2.42	2.23	2.64	3.09	2.80	3.37
East North Central (3)	966	41415208	2.33	400	41492735	0.96	2.42	2.15	2.72	1.37	1.19	1.54
West North Central (4)	707	19820152	3.57	299	19857254	1.51	2.37	2.07	2.71	2.06	1.75	2.37
South Atlantic (5)	4156	54010723	7.69	1191	54111827	2.20	3.50	3.28	3.73	5.49	5.23	5.76
East South Central (6)	1520	17044866	8.92	358	17076772	2.10	4.25	3.79	4.77	6.82	6.32	7.32
West South Central (7)	2756	39291440	7.01	873	39364991	2.22	3.16	2.93	3.41	4.80	4.50	5.10
Mountain (8)	653	22764925	2.87	297	22807540	1.30	2.20	1.92	2.53	1.57	1.30	1.83
Pacific (9)	1641	48162173	3.41	799	48252330	1.66	2.06	1.89	2.24	1.75	1.55	1.95

APPENDIX 3B (CONT.)

	Age 5–17 years											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	15167	967733271	1.57	5137	967710849	0.53	2.95	2.86	3.05	1.04	1.01	1.07
Sex												
Female	6539	473201470	1.38	2344	473145102	0.50	2.79	2.66	2.92	0.89	0.85	0.93
Male	7958	494531801	1.61	2591	494565787	0.52	3.07	2.94	3.21	1.09	1.04	1.13
Census Region												
Northeast (1)	2665	160020667	1.67	932	160016959	0.58	2.86	2.65	3.08	1.08	1.01	1.16
Midwest (2)	2563	209015145	1.23	894	209010303	0.43	2.87	2.66	3.09	0.80	0.74	0.85
South (3)	6685	365763983	1.83	2011	365755509	0.55	3.32	3.16	3.49	1.28	1.23	1.33
West (4)	3254	232933476	1.40	1300	232928079	0.56	2.50	2.35	2.67	0.84	0.78	0.90
Census Division												
New England (1)	584	41214998	1.42	209	41214043	0.51	2.79	2.39	3.27	0.91	0.78	1.04
Middle Atlantic (2)	2081	118805669	1.75	723	118802916	0.61	2.88	2.64	3.13	1.14	1.06	1.23
East North Central (3)	1624	144268398	1.13	546	144265055	0.38	2.97	2.70	3.28	0.75	0.68	0.81
West North Central (4)	939	64746748	1.45	348	64745247	0.54	2.70	2.39	3.05	0.91	0.80	1.02
South Atlantic (5)	3357	181032800	1.85	882	181028605	0.49	3.81	3.53	4.10	1.37	1.30	1.44
East South Central (6)	1158	57341859	2.02	282	57340530	0.49	4.11	3.61	4.68	1.53	1.40	1.66
West South Central (7)	2170	127389325	1.70	847	127386373	0.66	2.56	2.37	2.77	1.04	0.95	1.12
Mountain (8)	1014	74484273	1.36	396	74482548	0.53	2.56	2.28	2.88	0.83	0.73	0.93
Pacific (9)	2240	158449202	1.41	904	158445531	0.57	2.48	2.29	2.68	0.84	0.77	0.91

APPENDIX 3B (CONT.)

	Age ≥18 years											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	59651	4344550368	1.37	22025	4338570235	0.51	2.70	2.66	2.75	0.87	0.85	0.88
Sex												
Female	31602	2232460583	1.42	12397	2229528102	0.56	2.55	2.49	2.60	0.86	0.84	0.88
Male	25365	2112089785	1.20	8747	2109042132	0.41	2.90	2.83	2.97	0.79	0.77	0.80
Census Region												
Northeast (1)	11630	787743540	1.48	4398	786659202	0.56	2.64	2.55	2.73	0.92	0.89	0.95
Midwest (2)	12735	928501668	1.37	4948	927223574	0.53	2.57	2.49	2.66	0.84	0.81	0.87
South (3)	24207	1618862560	1.50	7801	1616634177	0.48	3.10	3.02	3.18	1.01	0.99	1.03
West (4)	11078	1009442600	1.10	4878	1008053090	0.48	2.27	2.19	2.35	0.61	0.59	0.64
Census Division												
New England (1)	3121	207592269	1.50	1380	207306516	0.67	2.26	2.12	2.41	0.84	0.77	0.90
Middle Atlantic (2)	8509	580151271	1.47	3018	579352686	0.52	2.82	2.70	2.93	0.95	0.91	0.98
East North Central (3)	7997	643192186	1.24	3196	642306824	0.50	2.50	2.40	2.60	0.75	0.71	0.78
West North Central (4)	4738	285309481	1.66	1752	284916750	0.61	2.70	2.56	2.85	1.05	0.99	1.10
South Atlantic (5)	12421	859197063	1.45	3984	858014368	0.46	3.11	3.00	3.23	0.98	0.95	1.01
East South Central (6)	4436	257490868	1.72	1320	257136429	0.51	3.36	3.16	3.57	1.21	1.15	1.27
West South Central (7)	7350	502174629	1.46	2497	501483380	0.50	2.94	2.81	3.08	0.97	0.93	1.00
Mountain (8)	3742	307072880	1.22	1692	306650190	0.55	2.21	2.09	2.34	0.67	0.62	0.71
Pacific (9)	7336	702369720	1.04	3186	701402900	0.45	2.30	2.21	2.40	0.59	0.56	0.62

[a] Rates per 100,000 population; [b] RR = incidence rate ratio comparing summer and winter rates

[d] CI = confidence interval; [d] RD = incidence rate difference per 100,000 population comparing summer and winter rates;

APPENDIX 3C.

Comparison of incidence rates of nontyphoidal salmonellosis serotypes by season and age group, U.S., 2010–2015

	Infants (< 1 year)									
	Summer		Winter		Comparison					
Serotype[a]	No.	Rate[b]	No.	Rate	RR[c]	95% CI[d]		RD[e]	95% CI	
Agona	68	0.10	26	-	-	-	-	-	-	-
Anatum	54	0.08	42	0.06	1.29	0.86	1.93	0.02	-0.01	0.04
Bareilly	140	0.20	34	0.05	4.13	2.84	6.00	0.15	0.11	0.19
Berta	35	0.05	11	-	-	-	-	-	-	-
Braenderup	85	0.12	54	0.08	1.58	1.12	2.22	0.04	0.01	0.08
Enteritidis	399	0.56	229	0.32	1.75	1.48	2.05	0.24	0.17	0.31
Heidelberg	175	0.25	143	0.20	1.23	0.98	1.53	0.05	0.00	0.09
I 4,[5],12:b:-	23	…	14	-	-	-	-	-	-	-
I 4,[5],12:i:-	253	0.36	153	0.21	1.66	1.36	2.03	0.14	0.09	0.20
Infantis	189	0.27	114	0.16	1.66	1.32	2.10	0.11	0.06	0.15
Javiana	895	1.26	164	0.23	5.47	4.63	6.46	1.03	0.94	1.12
Mbandaka	42	0.06	33	0.05	1.28	0.81	2.01	0.01	-0.01	0.04
Mississippi	198	0.28	23	-	-	-	-	-	-	-
Montevideo	339	0.48	94	0.13	3.61	2.88	4.54	0.34	0.29	0.40
Muenchen	437	0.61	117	0.16	3.74	3.05	4.59	0.45	0.39	0.52
Newport	1566	2.20	315	0.44	4.98	4.41	5.62	1.76	1.64	1.88
Oranienburg	141	0.20	89	0.12	1.59	1.22	2.07	0.07	0.03	0.12
Panama	28	-	9	-	-	-	-	-	-	-
Paratyphi B[f]	30	0.04	13	-	-	-	-	-	-	-
Poona	91	0.13	44	0.06	2.07	1.45	2.97	0.07	0.03	0.10
Rubislaw	182	0.26	67	0.09	2.72	2.06	3.60	0.16	0.12	0.21
Saintpaul	144	0.20	55	0.08	2.62	1.92	3.58	0.13	0.09	0.16
Sandiego	32	0.04	20	-	-	-	-	-	-	-
Schwarzengrund	118	0.17	40	0.06	2.96	2.07	4.23	0.11	0.08	0.14
Stanley	14	-	14	-	-	-	-	-	-	-
Subspecies I, Group O:4	41	0.06	25	-	-	-	-	-	-	-
Thompson	106	0.15	41	0.06	2.59	1.81	3.72	0.09	0.06	0.12
Typhimurium	909	1.28	463	0.65	1.97	1.76	2.20	0.63	0.53	0.73

APPENDIX 3C (CONT.)

	Age 1–4 years									
	Summer		Winter		Comparison					
Serotype[a]	No.	Rate[b]	No.	Rate	RR[c]	95% CI[d]		RD[e]	95% CI	
Agona	136	0.05	53	0.02	2.57	1.87	3.53	0.03	0.02	0.04
Anatum	17	-	17	-	-	-	-	-	-	-
Bareilly	145	0.05	29	-	-	-	-	-	-	-
Berta	98	0.03	28	-	-	-	-	-	-	-
Braenderup	150	0.05	53	0.02	2.84	2.07	3.88	0.03	0.02	0.04
Enteritidis	1268	0.44	623	0.22	2.04	1.85	2.24	0.22	0.19	0.25
Heidelberg	473	0.16	241	0.08	1.97	1.68	2.30	0.08	0.06	0.10
I 4,[5],12:b:-	95	0.03	32	0.01	2.97	1.99	4.44	0.02	0.01	0.03
I 4,[5],12:i:-	774	0.27	368	0.13	2.11	1.86	2.39	0.14	0.12	0.16
Infantis	258	0.09	112	0.04	2.31	1.85	2.88	0.05	0.04	0.06
Javiana	1553	0.54	244	0.08	6.38	5.57	7.30	0.45	0.42	0.48
Mbandaka	39	0.01	24	-	-	-	-	-	-	-
Mississippi	365	0.13	47	0.02	7.78	5.74	10.54	0.11	0.10	0.12
Montevideo	381	0.13	123	0.04	3.10	2.53	3.80	0.09	0.07	0.10
Muenchen	358	0.12	98	0.03	3.66	2.93	4.58	0.09	0.08	0.10
Newport	1753	0.61	307	0.11	5.72	5.07	6.46	0.50	0.47	0.53
Oranienburg	238	0.08	67	0.02	3.56	2.71	4.67	0.06	0.05	0.07
Panama	53	0.02	39	0.01	1.36	0.90	2.06	0.00	0.00	0.01
Paratyphi B[f]	99	0.03	61	0.02	1.63	1.18	2.24	0.01	0.00	0.02
Poona	216	0.07	67	0.02	3.23	2.46	4.25	0.05	0.04	0.06
Rubislaw	86	0.03	25	-	-	-	-	-	-	-
Saintpaul	259	0.09	134	0.05	1.94	1.57	2.39	0.04	0.03	0.06
Sandiego	71	0.02	43	0.01	1.65	1.13	2.42	0.01	0.00	0.02
Schwarzengrund	186	0.06	59	0.02	3.16	2.36	4.23	0.04	0.03	0.05
Stanley	93	0.03	64	0.02	1.46	1.06	2.00	0.01	0.00	0.02
Subspecies I, Group O:4	93	0.03	36	0.01	2.59	1.76	3.80	0.02	0.01	0.03
Thompson	108	0.04	37	0.01	2.92	2.01	4.25	0.02	0.02	0.03
Typhimurium	2491	0.86	1022	0.35	2.44	2.27	2.63	0.51	0.47	0.55

APPENDIX 3C (CONT.)

	Age 5–17 years									
	Summer		Winter		Comparison					
Serotype[a]	No.	Rate[b]	No.	Rate	RR[c]	95% CI[d]		RD[e]	95% CI	
Agona	97	0.01	39	0.00	2.49	1.72	3.61	0.01	0.00	0.01
Anatum	31	0.00	22	-	-	-	-	-	-	-
Bareilly	110	0.01	35	0.00	3.14	2.15	4.60	0.01	0.01	0.01
Berta	116	0.01	38	0.00	3.05	2.12	4.40	0.01	0.01	0.01
Braenderup	232	0.02	80	0.01	2.90	2.25	3.74	0.02	0.01	0.02
Enteritidis	2608	0.27	1133	0.12	2.30	2.15	2.47	0.15	0.14	0.16
Heidelberg	505	0.05	224	0.02	2.25	1.93	2.64	0.03	0.02	0.03
I 4,[5],12:b:-	95	0.01	38	0.00	2.50	1.72	3.64	0.01	0.00	0.01
I 4,[5],12:i:-	837	0.09	327	0.03	2.56	2.25	2.91	0.05	0.05	0.06
Infantis	263	0.03	101	0.01	2.60	2.07	3.28	0.02	0.01	0.02
Javiana	1169	0.12	193	0.02	6.06	5.20	7.05	0.10	0.09	0.11
Mbandaka	24	-	19	-	-	-	-	-	-	-
Mississippi	227	0.02	35	0.00	6.49	4.54	9.26	0.02	0.02	0.02
Montevideo	279	0.03	102	0.01	2.74	2.18	3.43	0.02	0.01	0.02
Muenchen	207	0.02	56	0.01	3.70	2.75	4.97	0.02	0.01	0.02
Newport	1454	0.15	286	0.03	5.08	4.48	5.77	0.12	0.11	0.13
Oranienburg	292	0.03	97	0.01	3.01	2.39	3.79	0.02	0.02	0.02
Panama	73	0.01	38	0.00	1.92	1.30	2.84	0.00	0.00	0.01
Paratyphi B[f]	172	0.02	53	0.01	3.25	2.39	4.42	0.01	0.01	0.02
Poona	240	0.02	46	0.00	5.22	3.81	7.15	0.02	0.02	0.02
Rubislaw	28	-	9	-	-	-	-	-	-	-
Saintpaul	316	0.03	125	0.01	2.53	2.06	3.11	0.02	0.02	0.02
Sandiego	85	0.01	32	0.00	2.66	1.77	3.99	0.01	0.00	0.01
Schwarzengrund	86	0.01	28	0.00	3.07	2.01	4.70	0.01	0.00	0.01
Stanley	94	0.01	45	0.00	2.09	1.46	2.98	0.01	0.00	0.01
Subspecies I, Group O:4	105	0.01	54	0.01	1.94	1.40	2.70	0.01	0.00	0.01
Thompson	217	0.02	63	0.01	3.44	2.60	4.56	0.02	0.01	0.02
Typhimurium	2686	0.28	851	0.09	3.16	2.92	3.41	0.19	0.18	0.20

APPENDIX 3C (CONT.)

	Age ≥18 years									
	Summer		Winter		Comparison					
Serotype[a]	No.	Rate[b]	No.	Rate	RR[c]	95% CI[d]		RD[e]	95% CI	
Agona	511	0.01	248	0.01	2.06	1.77	2.39	0.01	0.00	0.01
Anatum	462	0.01	210	0.00	2.20	1.87	2.59	0.01	0.00	0.01
Bareilly	647	0.01	202	0.00	3.20	2.73	3.75	0.01	0.01	0.01
Berta	506	0.01	174	0.00	2.90	2.44	3.45	0.01	0.01	0.01
Braenderup	1077	0.02	432	0.01	2.49	2.23	2.78	0.01	0.01	0.02
Enteritidis	12987	0.30	5238	0.12	2.48	2.40	2.56	0.18	0.17	0.18
Heidelberg	1379	0.03	627	0.01	2.20	2.00	2.41	0.02	0.02	0.02
I 4,[5],12:b:-	344	0.01	104	0.00	3.30	2.65	4.11	0.01	0.00	0.01
I 4,[5],12:i:-	2184	0.05	1044	0.02	2.09	1.94	2.25	0.03	0.02	0.03
Infantis	1485	0.03	637	0.01	2.33	2.12	2.55	0.02	0.02	0.02
Javiana	3748	0.09	730	0.02	5.13	4.74	5.55	0.07	0.07	0.07
Mbandaka	250	0.01	152	0.00	1.64	1.34	2.01	0.00	0.00	0.00
Mississippi	672	0.02	91	0.00	7.37	5.92	9.18	0.01	0.01	0.01
Montevideo	1271	0.03	463	0.01	2.74	2.46	3.05	0.02	0.02	0.02
Muenchen	1437	0.03	462	0.01	3.11	2.80	3.45	0.02	0.02	0.02
Newport	7808	0.18	1630	0.04	4.78	4.53	5.05	0.14	0.14	0.15
Oranienburg	990	0.02	397	0.01	2.49	2.22	2.80	0.01	0.01	0.02
Panama	246	0.01	107	0.00	2.30	1.83	2.88	0.00	0.00	0.00
Paratyphi B[f]	465	0.01	186	0.00	2.50	2.11	2.96	0.01	0.01	0.01
Poona	411	0.01	117	0.00	3.51	2.86	4.31	0.01	0.01	0.01
Rubislaw	95	0.00	40	0.00	2.37	1.64	3.43	0.00	0.00	0.00
Saintpaul	1113	0.03	513	0.01	2.17	1.95	2.41	0.01	0.01	0.02
Sandiego	166	0.00	107	0.00	1.55	1.22	1.98	0.00	0.00	0.00
Schwarzengrund	239	0.01	109	0.00	2.19	1.75	2.75	0.00	0.00	0.00
Stanley	197	0.00	121	0.00	1.63	1.30	2.04	0.00	0.00	0.00
Subspecies I, Group O:4	324	0.01	152	0.00	2.13	1.76	2.58	0.00	0.00	0.00
Thompson	1021	0.02	342	0.01	2.98	2.64	3.37	0.02	0.01	0.02
Typhimurium	6415	0.15	2411	0.06	2.66	2.54	2.78	0.09	0.09	0.10

[a] 28 of 40 most common serotypes for all ages, LEDS, 1996–2015. Results not shown for 12 serotypes w/ suppressed rates in ≥3 age groups: Brandenburg, Derby, Dublin, Give, Hadar, Hartford, Litchfield, Norwich, Seftenberg, Subspecies I, Subspecies I Group O:7, Subspecies I Group O:9.

[b] Rates per 100,000 population. Rates not presented when numerator averaged < 5 events/year (ie., <30 over six years), as these are statistically unstable. Population estimates by age group and season (Summer/Winter) for rate denominators: Infants < 1 year (71118861/71275500); 1–4 years (288738075/289278573); 5–17 years (967733271/967710849); ≥18 (4344550368/4338570043)

APPENDIX 3D.

Comparison of incidence rates of nontyphoidal salmonellosis among infants by season, infant age group, sex, and geography, 2010–2015

	< 3 months											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	2194	17779715	12.34	846	17818875	4.75	2.60	2.40	2.81	7.59	6.98	8.20
Sex												
Female	950	8688095	10.93	364	8707069	4.18				6.75	5.94	7.57
Male	1096	9091621	12.06	416	9111806	4.57	2.64	2.36	2.96	7.49	6.65	8.33
Census Region												
Northeast (1)	308	2862024	10.76	148	2868327	5.16	2.09	1.71	2.54	5.60	4.14	7.06
Midwest (2)	232	3747842	6.19	124	3756096	3.30	1.88	1.51	2.33	2.89	1.90	3.87
South (3)	1392	6805419	20.45	453	6820408	6.64	3.08	2.77	3.42	13.81	12.58	15.05
West (4)	262	4364431	6.00	120	4374044	2.74	2.19	1.76	2.72	3.26	2.38	4.14
Census Division												
New England (1)	49	683526	7.17	17	685032	-	-	-	-	-	-	-
Middle Atlantic (2)	259	2178498	11.89	131	2183296	6.00	1.98	1.61	2.44	5.89	4.11	7.66
East North Central (3)	128	2526630	5.07	71	2532195	2.80	1.81	1.35	2.41	2.26	1.17	3.36
West North Central (4)	104	1221211	8.52	53	1223901	4.33	1.97	1.41	2.74	4.19	2.18	6.20
South Atlantic (5)	623	3325231	18.74	192	3332555	5.76	3.25	2.77	3.82	12.97	11.29	14.66
East South Central (6)	264	1045628	25.25	70	1047931	6.68	3.78	2.90	4.92	18.57	15.14	21.99
West South Central (7)	505	2434560	20.74	191	2439922	7.83	2.65	2.24	3.13	12.91	10.79	15.04
Mountain (8)	101	1385931	7.29	59	1388984	4.25	1.72	1.24	2.37	3.04	1.25	4.83
Pacific (9)	161	2978500	5.41	61	2985060	2.04	2.65	1.97	3.55	3.36	2.38	4.34

APPENDIX 3D (CONT.)

	3–5 months											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	2859	17779715	16.08	1204	17818875	6.76	2.38	2.22	2.55	9.32	8.62	10.03
Sex												
Female	1234	8688095	14.20	514	8707069	5.90				8.30	7.36	9.24
Male	1467	9091621	16.14	619	9111806	6.79	2.38	2.16	2.61	9.34	8.36	10.33
Census Region												
Northeast (1)	331	2862024	11.57	146	2868327	5.09	2.27	1.87	2.76	6.48	4.98	7.97
Midwest (2)	274	3747842	7.31	181	3756096	4.82	1.52	1.26	1.83	2.49	1.38	3.61
South (3)	1944	6805419	28.57	702	6820408	10.29	2.78	2.55	3.03	18.27	16.79	19.75
West (4)	310	4364431	7.10	175	4374044	4.00	1.78	1.48	2.14	3.10	2.11	4.09
Census Division												
New England (1)	56	683526	8.19	28	685032	-	-	-	-	-	-	-
Middle Atlantic (2)	275	2178498	12.62	118	2183296	5.40	2.34	1.88	2.90	7.22	5.44	9.00
East North Central (3)	153	2526630	6.06	116	2532195	4.58	1.32	1.04	1.68	1.47	0.20	2.75
West North Central (4)	121	1221211	9.91	65	1223901	5.31	1.87	1.38	2.52	4.60	2.41	6.78
South Atlantic (5)	887	3325231	26.67	314	3332555	9.42	2.83	2.49	3.22	17.25	15.21	19.29
East South Central (6)	330	1045628	31.56	92	1047931	8.78	3.59	2.85	4.53	22.78	18.93	26.63
West South Central (7)	727	2434560	29.86	296	2439922	12.13	2.46	2.15	2.82	17.73	15.16	20.30
Mountain (8)	116	1385931	8.37	88	1388984	6.34	1.32	1.00	1.74	2.03	0.02	4.05
Pacific (9)	194	2978500	6.51	87	2985060	2.91	2.23	1.74	2.88	3.60	2.50	4.70

APPENDIX 3D (CONT.)

	6–8 months											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	2157	17779715	12.13	868	17818875	4.87	2.49	2.30	2.69	7.26	6.65	7.87
Sex												
Female	992	8688095	11.42	377	8707069	4.33	2.64	2.34	2.97	7.09	6.25	7.92
Male	1044	9091621	11.48	454	9111806	4.98	2.30	2.06	2.57	6.50	5.67	7.33
Census Region												
Northeast (1)	294	2862024	10.27	106	2868327	3.70	2.78	2.23	3.47	6.58	5.21	7.95
Midwest (2)	195	3747842	5.20	118	3756096	3.14	1.66	1.32	2.08	2.06	1.14	2.99
South (3)	1386	6805419	20.37	489	6820408	7.17	2.84	2.56	3.15	13.20	11.95	14.44
West (4)	282	4364431	6.46	155	4374044	3.54	1.82	1.50	2.22	2.92	1.98	3.86
Census Division												
New England (1)	40	683526	5.85	13	685032	-	-	-	-	-	-	-
Middle Atlantic (2)	254	2178498	11.66	93	2183296	4.26	2.74	2.16	3.47	7.40	5.72	9.07
East North Central (3)	118	2526630	4.67	68	2532195	2.69	1.74	1.29	2.34	1.98	0.93	3.04
West North Central (4)	77	1221211	6.31	50	1223901	4.09	1.54	1.08	2.20	2.22	0.41	4.03
South Atlantic (5)	621	3325231	18.68	209	3332555	6.27	2.98	2.55	3.48	12.40	10.71	14.10
East South Central (6)	219	1045628	20.94	66	1047931	6.30	3.33	2.53	4.38	14.65	11.48	17.81
West South Central (7)	546	2434560	22.43	214	2439922	8.77	2.56	2.18	2.99	13.66	11.44	15.87
Mountain (8)	86	1385931	6.21	67	1388984	4.82	1.29	0.93	1.77	1.38	-0.37	3.13
Pacific (9)	196	2978500	6.58	88	2985060	2.95	2.23	1.74	2.87	3.63	2.52	4.74

APPENDIX 3D (CONT.)

	9–11 months											
	Summer			Winter			Comparison					
	No. of cases	Population	Rate[a]	No. of cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	2105	17779715	11.84	779	17818875	4.37	2.71	2.49	2.94	7.47	6.88	8.06
Sex												
Female	899	8688095	10.35	320	8707069	3.68	2.82	2.48	3.20	6.67	5.89	7.46
Male	1073	9091621	11.80	412	9111806	4.52	2.61	2.33	2.92	7.28	6.45	8.11
Census Region												
Northeast (1)	278	2862024	9.71	108	2868327	3.77	2.58	2.07	3.22	5.95	4.60	7.29
Midwest (2)	155	3747842	4.14	98	3756096	2.61	1.59	1.23	2.04	1.53	0.70	2.36
South (3)	1430	6805419	21.01	424	6820408	6.22	3.38	3.03	3.77	14.80	13.56	16.04
West (4)	242	4364431	5.54	149	4374044	3.41	1.63	1.33	2.00	2.14	1.25	3.03
Census Division												
New England (1)	59	683526	8.63	28	685032	-	-	-	-	-	-	-
Middle Atlantic (2)	219	2178498	10.05	80	2183296	3.66	2.74	2.12	3.54	6.39	4.83	7.94
East North Central (3)	79	2526630	3.13	62	2532195	2.45	1.28	0.92	1.78	0.68	-0.24	1.60
West North Central (4)	76	1221211	6.22	36	1223901	2.94	2.12	1.42	3.15	3.28	1.58	4.98
South Atlantic (5)	654	3325231	19.67	182	3332555	5.46	3.60	3.06	4.24	14.21	12.50	15.91
East South Central (6)	211	1045628	20.18	64	1047931	6.11	3.30	2.50	4.37	14.07	10.97	17.18
West South Central (7)	565	2434560	23.21	178	2439922	7.30	3.18	2.69	3.76	15.91	13.72	18.11
Mountain (8)	87	1385931	6.28	58	1388984	4.18	1.50	1.08	2.10	2.10	0.40	3.80
Pacific (9)	155	2978500	5.20	91	2985060	3.05	1.71	1.32	2.21	2.16	1.12	3.19

[a] Rates per 100,000 population; [b] RR = incidence rate ratio comparing summer and winter rates

[c] CI = confidence interval; [d] RD = incidence rate difference per 100,000 population comparing summer and winter rates

APPENDIX 3E.

Comparison of incidence rates of nontyphoidal salmonellosis by extended season, age group, sex, and geography, 2010–2015

	Infants (< 1 year)											
	Summer + September			Winter+March			Comparison					
	Cases	Population	Rate[a]	Cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	12972	94840220	13.68	4866	95017820	5.12	2.67	2.58	2.76	8.56	8.28	8.83
Sex												
Female	5659	46343387	12.21	2066	46429726	4.45	2.74	2.61	2.89	7.76	7.39	8.13
Male	6515	48496833	13.43	2529	48588096	5.20	2.58	2.47	2.70	8.23	7.84	8.61
Census Region												
Northeast (1)	1533	15268060	10.04	717	15291182	4.69	2.14	1.96	2.34	5.35	4.74	5.96
Midwest (2)	1184	19993639	5.92	708	20023917	3.54	1.67	1.53	1.84	2.39	1.96	2.81
South (3)	8800	36304921	24.24	2646	36359900	7.28	3.33	3.19	3.48	16.96	16.38	17.54
West (4)	1455	23282964	6.25	794	23318223	3.41	1.84	1.68	2.00	2.84	2.45	3.24
Census Division												
New England (1)	262	3646412	7.19	117	3651934	3.20	2.24	1.80	2.79	3.98	2.94	5.03
Middle Atlantic (2)	1271	11621649	10.94	600	11639248	5.15	2.12	1.93	2.34	5.78	5.05	6.51
East North Central (3)	657	13478833	4.87	429	13499245	3.18	1.53	1.36	1.73	1.70	1.22	2.18
West North Central (4)	527	6514806	8.09	279	6524672	4.28	1.89	1.64	2.19	3.81	2.96	4.67
South Atlantic (5)	3953	17739137	22.28	1158	17766000	6.52	3.42	3.20	3.65	15.77	14.98	16.56
East South Central (6)	1452	5578120	26.03	363	5586568	6.50	4.01	3.57	4.49	19.53	18.04	21.03
West South Central (7)	3395	12987664	26.14	1125	13007332	8.65	3.02	2.83	3.23	17.49	16.48	18.51
Mountain (8)	527	7393537	7.13	359	7404734	4.85	1.47	1.29	1.68	2.28	1.49	3.07
Pacific (9)	928	15889427	5.84	435	15913489	2.73	2.14	1.91	2.39	3.11	2.65	3.56

APPENDIX 3E (CONT.)

	Age 1–4 years											
	Summer + September			Winter+March			Comparison					
	Cases	Population	Rate[a]	Cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	19737	384955367	5.13	6910	385706605	1.79	2.86	2.78	2.94	3.34	3.25	3.42
Sex												
Female	8825	188281707	4.69	3218	188663743	1.71	2.75	2.64	2.86	2.98	2.87	3.10
Male	9832	196673660	5.00	3425	197042862	1.74	2.88	2.77	2.99	3.26	3.15	3.38
Census Region												
Northeast (1)	2905	61632830	4.71	1321	61744701	2.14	2.20	2.06	2.35	2.57	2.37	2.78
Midwest (2)	2179	81640146	2.67	953	81788332	1.17	2.29	2.12	2.47	1.50	1.37	1.64
South (3)	11613	147116755	7.89	3143	147383789	2.13	3.70	3.56	3.85	5.76	5.60	5.92
West (4)	3040	94561355	3.21	1493	94732995	1.58	2.04	1.92	2.17	1.64	1.50	1.78
Census Division												
New England (1)	546	15040950	3.63	255	15068251	1.69	2.15	1.85	2.49	1.94	1.57	2.31
Middle Atlantic (2)	2359	46591880	5.06	1066	46676450	2.28	2.22	2.06	2.38	2.78	2.53	3.03
East North Central (3)	1245	55215542	2.25	562	55315765	1.02	2.22	2.01	2.45	1.24	1.09	1.39
West North Central (4)	934	26424603	3.53	391	26472567	1.48	2.39	2.13	2.69	2.06	1.79	2.33
South Atlantic (5)	5695	72008122	7.91	1499	72138825	2.08	3.81	3.60	4.03	5.83	5.60	6.06
East South Central (6)	2088	22724539	9.19	458	22765786	2.01	4.57	4.13	5.05	7.18	6.74	7.61
West South Central (7)	3830	52384094	7.31	1186	52479178	2.26	3.24	3.03	3.45	5.05	4.79	5.32
Mountain (8)	888	30350631	2.93	417	30405721	1.37	2.13	1.90	2.40	1.55	1.32	1.79
Pacific (9)	2152	64210724	3.35	1076	64327274	1.67	2.00	1.86	2.16	1.68	1.51	1.85

APPENDIX 3E (CONT.)

	Age 5–17 years											
	Summer + September			Winter+March			Comparison					
	Cases	Population	Rate[a]	Cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	20043	1290286074	1.55	6959	1290309559	0.54	2.88	2.80	2.96	1.01	0.99	1.04
Sex												
Female	8635	630933910	1.37	3181	630864586	0.50	2.71	2.61	2.83	0.86	0.83	0.90
Male	10479	659352164	1.59	3520	659445028	0.53	2.98	2.87	3.09	1.06	1.02	1.09
Census Region												
Northeast (1)	3479	213353934	1.63	1311	213365075	0.61	2.65	2.49	2.83	1.02	0.95	1.08
Midwest (2)	3236	278677776	1.16	1227	278692329	0.44	2.64	2.47	2.82	0.72	0.67	0.77
South (3)	9121	487669414	1.87	2638	487694880	0.54	3.46	3.31	3.61	1.33	1.29	1.37
West (4)	4207	310567844	1.35	1783	310584062	0.57	2.36	2.23	2.49	0.78	0.73	0.83
Census Division												
New England (1)	767	54951539	1.40	301	54954409	0.55	2.55	2.23	2.91	0.85	0.73	0.96
Middle Atlantic (2)	2712	158402395	1.71	1010	158410667	0.64	2.69	2.50	2.89	1.07	1.00	1.15
East North Central (3)	2027	192351594	1.05	737	192361638	0.38	2.75	2.53	2.99	0.67	0.62	0.72
West North Central (4)	1209	86326183	1.40	490	86330691	0.57	2.47	2.22	2.74	0.83	0.74	0.93
South Atlantic (5)	4581	241369198	1.90	1144	241381802	0.47	4.00	3.75	4.27	1.42	1.36	1.49
East South Central (6)	1594	76453320	2.08	360	76457312	0.47	4.43	3.95	4.96	1.61	1.50	1.73
West South Central (7)	2946	169846896	1.73	1134	169855766	0.67	2.60	2.43	2.78	1.07	0.99	1.14
Mountain (8)	1341	99309127	1.35	541	99314313	0.54	2.48	2.24	2.74	0.81	0.72	0.89
Pacific (9)	2866	211258717	1.36	1242	211269748	0.59	2.31	2.16	2.47	0.77	0.71	0.83

APPENDIX 3E (CONT.)

	Age ≥18 years											
	Summer + September			Winter+March			Comparison					
	Cases	Population	Rate[a]	Cases	Population	Rate	RR[b]	95% CI[c]		RD[d]	95% CI	
Total	78462	5795454582	1.35	30119	5782080387	0.52	2.60	2.56	2.63	0.83	0.82	0.84
Sex												
Female	41496	2977941697	1.39	16924	2971389734	0.57	2.45	2.40	2.49	0.82	0.81	0.84
Male	33460	2817512885	1.19	11990	2810690916	0.43	2.78	2.73	2.84	0.76	0.75	0.78
Census Region												
Northeast (1)	14766	1051056462	1.40	6089	1048586468	0.58	2.42	2.35	2.49	0.82	0.80	0.85
Midwest (2)	16696	1238864716	1.35	6818	1235953370	0.55	2.44	2.38	2.51	0.80	0.77	0.82
South (3)	32500	2159987189	1.50	10504	2154911194	0.49	3.09	3.02	3.16	1.02	1.00	1.04
West (4)	14499	1346861146	1.08	6706	1343696007	0.50	2.16	2.10	2.22	0.58	0.56	0.60
Census Division												
New England (1)	3971	276982527	1.43	1930	276331614	0.70	2.05	1.94	2.17	0.74	0.68	0.79
Middle Atlantic (2)	10795	774073936	1.39	4159	772254853	0.54	2.59	2.50	2.68	0.86	0.83	0.89
East North Central (3)	10454	858187048	1.22	4376	856170299	0.51	2.38	2.30	2.47	0.71	0.68	0.73
West North Central (4)	6242	380677668	1.64	2442	379783072	0.64	2.55	2.43	2.67	1.00	0.95	1.04
South Atlantic (5)	16446	1146394200	1.43	5380	1143700161	0.47	3.05	2.96	3.15	0.96	0.94	0.99
East South Central (6)	5796	343560343	1.69	1755	342752972	0.51	3.29	3.12	3.48	1.18	1.13	1.22
West South Central (7)	10258	670032646	1.53	3369	668458062	0.50	3.04	2.92	3.16	1.03	0.99	1.06
Mountain (8)	4912	409715749	1.20	2316	408752912	0.57	2.12	2.01	2.22	0.63	0.59	0.67
Pacific (9)	9587	937145397	1.02	4390	934943095	0.47	2.18	2.10	2.26	0.55	0.53	0.58

[a] Rates per 100,000 population; [b] RR = incidence rate ratio comparing extended summer and winter rates

[c] CI = confidence interval; [d] RD = incidence rate difference per 100,000 population comparing extended summer and winter rates

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CURRICULUM VITAE

Kathleen M. Fitzsimmons
fitzsimmonskm@gmail.com

EDUCATION

1/20	**Boston University School of Public Health**, Boston, MA *Doctor of Philosophy in Epidemiology* Honors:
9/14–5/16	Boston University School of Public Health Training Program in Reproductive, Perinatal, and Pediatric Epidemiology (BURPPE)
5/06	**Boston University School of Public Health**, Boston, MA *Master of Public Health in Epidemiology* Honors:
5/06	Delta Omega Honorary Society in Public Health, Alpha Beta Chapter
5/01	**Colgate University**, Hamilton, NY *Bachelor of Arts in Biology, Cum Laude* Honors:
9/98–5/01	Dean's Award for Academic Excellence
9/99	Beta-Beta-Beta Biological Honor Society
1/00–5/00	Cardiff University, Wales natural science study abroad program
5/01	Manzi Fellowship for commitment to community service

WORK EXPERIENCE

12/08–	**Massachusetts Department of Public Health**, Boston, MA *Epidemiologist, Occupational Health Surveillance Program (OHSP)* *Co-Principal Investigator, OHSP Work-Related Lung Disease Project*
12/08–12/13	**Massachusetts Department of Public Health**, Boston, MA *Epidemiologist, Asthma Prevention and Control Program*
10/06–10/08	**California Department of Public Health**, Richmond, CA *CDC/CSTE Applied Epidemiology Fellow, Environmental Health*
7/02–9/06	**Boston University School of Medicine**, Boston, MA *Research Technician, Pulmonary Center*
1/06–5/06	**Massachusetts Department of Public Health, State Laboratory Institute**, Boston, MA *Intern, Mycobacteriology Laboratory*

TEACHING EXPERIENCE

	Boston University School of Public Health, Boston, MA
6/13–8/13	*Graduate Teaching Assistant, Introduction to Epidemiology*
1/05–5/05	*Graduate Teaching Assistant, Infectious Disease Epidemiology*
6/09	**University of New Hampshire School of Health and Human Services**, Manchester, NH *Guest Lecturer, Work Environment Policy and the Health of Workers*

PRESENTATIONS

Fitzsimmons K, Pechter E, McKenna M. Asthma among School Staff in Massachusetts: Using Industry and Occupation Information from the 2011–2015 Massachusetts Behavioral Risk Factor Surveillance System. 2018 CDC BRFSS Training Workshop. Abstract accepted for Presentation. April 2018.

Fitzsimmons K, Davis L. Elevated Asthma Prevalence among Home Care Aides: Using Industry and Occupation Information from the 2011–2015 Massachusetts Behavioral Risk Factor Surveillance System. 2017 CSTE Annual Conference. Oral Presentation. June 2017.

Fitzsimmons K, Pechter E, McKenna M, Davis L. Elevated Asthma Prevalence among Child Care Workers: Using Industry Information from the 2011–2013 Massachusetts Behavioral Risk Factor Surveillance System. 2015 CSTE Annual Conference. Oral Presentation. June 2015.

Fitzsimmons K, Tak S, Pechter E, Davis L. On-the-job exposure to environmental tobacco smoke among Massachusetts workers. 2013 APHA Annual Meeting. Oral Presentation. November 2013.

Fitzsimmons K, Harrison R. Occupational Heat-related Illness. Boston University Gijs Van Seventer Environmental Health Seminar. Oral Presentation. October 2012.

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Fitzsimmons K, Harrison R. Occupational Heat-Related Illness: Importance, Risk Factors, and Prevention. 2008 CSTE Annual Conference. Oral Presentation. June 2008.

Fitzsimmons K, Harrison R. Tracking Occupational Heat-Related Illness in California, 2000–2007. 2008 CSTE Annual Conference. Oral Presentation. June 2008.

Fitzsimmons K, Harrison R. Occupational Heat-Related Illness in California. 2008 California Public Health Association – North Meeting. Oral Presentation. March 2008.

Fitzsimmons K, Flattery J, Martysh E, Harrison R. Evaluation of Work-Related Asthma Surveillance in California. 2007 CSTE Annual Conference. Poster. June 2007.

PUBLICATIONS

Peer-reviewed journal articles:

Rosenman KD, Reilly MJ, Pechter E, **Fitzsimmons K**, Flattery J, Weinberg J, et al. Cleaning products and work-related asthma, 10 year update. JOEM. 2019; Accepted for publication 10/2019.

Lefkowitz D, Pechter E, **Fitzsimmons K**, Lumia M, Stephens AC, Davis L, et al. Isocyanates and work-related asthma: Findings from California, Massachusetts, Michigan, and New Jersey, 1993–2008. Am J Ind Med. 2015;58(11):1138–49.

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Massachusetts Department of Public Health (Fall 2013). *On-the-job exposure to environmental tobacco smoke (ETS) in Massachusetts.* Occupational Lung Disease Bulletin.

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Massachusetts Department of Public Health (May 2011). *Asthma among Older Adults in Massachusetts.* Asthma Prevention and Control Program Data Bulletin.

Massachusetts Department of Public Health (August 2010). *Work-Related Asthma Surveillance, Massachusetts, 1995–2008.* Occupational Lung Disease Bulletin.

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California Department of Public Health. (July 2007). *Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies .Report No.1: Heat-Related Illness and Mortality*.

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“Gaps seen in exposure to smoke on the job”. News Article. The Boston Globe. 11/4/13.

“Reducing Worker Exposure to ETS”. NIOSH Science Blog. 11/21/2013.

“On-the-job Exposure to Environmental Tobacco Smoke“. NIOSH eNews. 12/2013.

PARTICIPATION IN PROFESSIONAL AND ACADEMIC ORGANIZATIONS

2015–2016	Participant, BUSPH Doctoral Student Organization
2015, 2017–2019	Member, Society for Epidemiologic Research (SER)
2006–2019	Member, Council of State and Territorial Epidemiologists (CSTE)
2008, 2013–2019	Member, American Public Health Association (APHA)
2009–2011	External Reviewer, CDC/CSTE Applied Epidemiology Fellowship Program