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Climate change, extreme events and increased risk of salmonellosis in Maryland, USA: Evidence for coastal vulnerability

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ABSTRACT

Background: Salmonella is a leading cause of acute gastroenteritis worldwide. Patterns of salmonellosis have been linked to weather events. However, there is a dearth of data regarding the association between extreme events and risk of salmonellosis, and how this risk may disproportionately impact coastal communities.
Methods: We obtained *Salmonella* case data from the Maryland Foodborne Diseases Active Surveillance Network (2002–2012), and weather data from the National Climatic Data Center (1960–2012). We developed exposure metrics related to extreme temperature and precipitation events using a 30 year baseline (1960–1989) and linked them with county-level salmonellosis data. Data were analyzed using negative binomial Generalized Estimating Equations.
Results: We observed a 4.1% increase in salmonellosis risk associated with a 1 unit increase in extreme temperature events (incidence rate ratio (IRR):1.041; 95% confidence interval (CI):1.013–1.069). This increase in risk was more pronounced in coastal versus non-coastal areas (5.1% vs 1.5%). Likewise, we observed a 5.6% increase in salmonellosis risk (IRR:1.056; CI:1.035–1.078) associated with a 1 unit increase in extreme precipitation events, with the impact disproportionately felt in coastal areas (7.1% vs 3.6%).
Conclusions: To our knowledge, this is the first empirical evidence showing that extreme temperature/precipitation events—that are expected to be more frequent and intense in coming decades—are disproportionately impacting coastal communities with regard to salmonellosis. Adaptation strategies need to account for this differential burden, particularly in light of ever increasing coastal populations.

1. Introduction

Salmonella causes an estimated 1.2 million cases of acute gastroenteritis, including 23,000 hospitalizations and 450 deaths, in the United States each year (Scallan et al., 2011). In Maryland, 9529 cases of culture-confirmed cases of *Salmonella* infections were reported to the FoodNet program between 2002 and 2012. *Salmonella* infections have been attributed to a number of diverse sources, including produce, meats and eggs (Pires et al., 2014). Salmonellosis typically self-resolves in 5–7 days, although more serious sequelae, including septicemias and infections in immunocompromised individuals, require medical treatment (Hohmann, 2001). *Salmonella* infections proliferate during seasons characterized by elevated temperatures and precipitation, which can amplify bacterial replication and transmission to surface water and food crops, potential sources of infection (Grjibovski et al., 2014; Haley et al., 2009; Kovats et al., 2004; Lal et al., 2013; Micallef et al., 2012; Zhang et al., 2010).

Global climate change is expected to increase the frequency and intensity of extreme temperature and precipitation events (IPCC, 2013). A recent report by the Intergovernmental Panel for Climate Change (IPCC) suggests that recent trends in extreme temperature and precipitation events will continue to increase in future decades with more frequent and longer lasting heat waves (IPCC, 2013). A recent time series analysis also demonstrated a continued global increase in the frequency of the most extreme hot days over land, even during the hypothesized "global warming hiatus"(Seneviratne et al., 2014). Likewise, it is estimated that the frequency of extreme El Niño events—characterized by increased extreme heat days and heavy precipitation—will continue to rise in response to continued greenhouse warming (Cai et al., 2014).

Recent studies have provided evidence of an association between weather events and the incidence of *Salmonella* infections (Kovats

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et al., 2004; Zhang et al., 2010). For example, previous time-series studies have identified associations between average temperature and the number of reported cases of *Salmonella* infection (Kovats et al., 2004; Zhang et al., 2010). These studies focused on short term weather rather than long term anomalies, such as changes in extreme temperature and precipitation events in the context of local climate. Others have hypothesized that the impacts of climate change on rates of food- and waterborne diseases will be more pronounced in coastal communities (Semenza et al., 2012). Coastal communities are more vulnerable to increased flooding events that can bring water contaminated with bacterial pathogens (originating from point sources such as municipal wastewater treatment plants and animal feeding operations) into close proximity with individuals living in impacted coastal communities (Semenza et al., 2012). However, to the best of our knowledge, no quantitative estimates have been generated that describe the potential differential impacts of climate change on food- and waterborne disease—including salmonellosis—in coastal versus non-coastal areas.

In this study, we investigated the association between long term alterations in extreme temperature and precipitation events and the incidence of salmonellosis in Maryland, USA. Furthermore, we present the first ever quantitative estimates providing evidence that climate change disproportionately impacts coastal communities with regard to the burden of salmonellosis, a leading cause of food- and waterborne disease worldwide.

2. Methods

2.1. Study site

Maryland, a state located in the Mid-Atlantic, United States, has a population of approximately 5.98 million, and is classified as having a temperate climate marked by four distinct seasons (Maryland State Archives, 2014). The average temperatures in summer and winter are 22.6 °C and 1.17 °C, respectively (Maryland State Archives, 2014). The Chesapeake Bay (the largest estuary in the United States) bisects the state into two shores, the Eastern and Western Shores. The Eastern Shore is a flat, low-lying coastal zone, dissected by numerous tidal tributaries draining into the Chesapeake Bay and Coastal Bays, with agricultural and forested areas representing the largest land uses (Maryland Department of Planning, 2015). In contrast, the Western Maryland is characterized by an average land elevation that is significantly higher and steeper than that of the Eastern Shore. In addition, the Western Maryland is represented by more commercial, industrial and residential land uses compared with the Eastern Shore (Maryland Department of Planning, 2015).

2.2. Salmonella case data

We obtained *Salmonella* case data from the Maryland Foodborne Diseases Active Surveillance Network (FoodNet). The Maryland FoodNet program is 1 of 10 FoodNet sites funded by the Centers for Disease Control and Prevention; it conducts active surveillance on culture-confirmed cases of *Salmonella*, as well as 9 other pathogens. We focused on culture-confirmed cases of salmonellosis occurring in Maryland between 2002 and 2012. We defined a case as an individual whose biological specimen (stool, blood, or other) was culture confirmed for the presence of *Salmonella*, regardless of symptoms or date of onset.

2.3. Demographic data

We obtained age, sex and race data from the 2010 Census of Population and Housing, Summary File 1 and poverty data from the American Community Survey 2006–2010 (US Department of Commerce, 2014). These data were downloaded at the county level from the Census website and used to calculate county level percentages of 1) people in the age groups <5, 5–17, 18–64, and ≥65; 2) individuals living below the poverty level in 2010; 3) populations of individual races; and 4) males and females.

2.4. Coastal community definition

Counties were categorized as "coastal" and "non-coastal" based on Maryland Department of Natural Resources definitions (http://www.dnr.state.md.us/ccs/where_we_work.asp). Coastal counties are geographically situated in the Maryland coastal zone and the Chesapeake Bay watershed area (Supplemental materials, Fig. S2). Non-coastal counties lie in the Chesapeake Bay watershed but are not situated in the Maryland coastal zone.

2.5. Weather data and computation of exceedance days

We obtained daily weather data from the National Climatic Data Center website for the 1960–2012 period, including daily maximum temperature (TMAX) and precipitation (PRCP) (NOAA National Climatic Data Center, 2013). If a county had multiple stations, we used averaged daily TMAX and PRCP values. If no station data were available, we borrowed information from stations that were located within a 30 km radius of the county boundary or set it to "missing" if no stations were available within the 30 km radius. In the complete dataset, 99% of all counties had less than 1.5% missing data and there was no spatial pattern with regard to the location of missing data.

Using daily TMAX and PRCP for the 1960–1989 period, we computed county-specific 30 year baselines for a given calendar day using a 31 day window that centered around the particular calendar day. For example, the baseline data for Baltimore County for May 25th consisted of all daily observations for Baltimore County from May 10th to June 9 from 1960 to 1989. Based on the distribution of this data, we identified the 90th and 95th percentile values of PRCP and TMAX, referred to as Extreme Precipitation Threshold 90th percentile (EPT_{90}) and Extreme Temperature Threshold 95th percentile (ETT_{95}). Calendar day specific PRCP and TMAX values for each county were compared with their respective EPT_{90} and ETT_{95} and assigned a value of "1" if they exceeded the thresholds, and "0" otherwise. We then summed these "exceedance days" over the calendar month for each county during the 2002–2012 period, for which we have the FoodNet data.

2.6. Statistical model

We used negative binomial generalized estimating equations (GEE) (Byers et al., 2003; Greene, 1994) to investigate the relationship between EPT_{90} and ETT_{95} exceedance events and salmonellosis risk in all 24 Maryland counties for the 2002–2012 period. First, we ran an overall analysis that included the entire study population, adjusting for potential confounders including poverty status, age, sex and race. Following this, we ran restricted analyses that focused on specific age groups (<5, 5–17, 18–64, ≥65), race (non-Hispanic White, non-Hispanic Black), sex (male, female), season (Spring, Summer, Fall, Winter) and geographic location (coastal counties, non-coastal counties). The PROC GENMOD command with REPEATED statement was used for controlling the autocorrelation of repeated measurements within each county. We performed all statistical analyses in SAS 9.4 (Cary, NC, USA).

3. Results

A total of 9529 culture-confirmed cases of *Salmonella* infection were reported to the Maryland FoodNet system between 2002 and 2012 (Table 1). The majority of cases were among adults aged 18 to 64 years (46.8%), with females representing a slight majority of cases (52.7%) and non-Hispanic Whites representing the racial majority of cases (39.4%) (Table 1).

Table 1
Characteristics of reported *Salmonellosis* cases: Maryland, 2002–2012.

Characteristic		# Cases	% of Cases	Composition of MD population (%)
Age				
	<5	2380	25	6.3
	5–17	1661	17.4	17
	18–6	4462	46.8	64.3
	≥65	979	10.3	12.4
	Unreported	47	0.5	NA
Gender				
	Female	5023	52.7	50.9
	Male	4475	47	49.1
	Unreported	31	0.3	NA
Race				
	Non-Hispanic White	3755	39.4	54.7
	Non-Hispanic Blacks	2509	26.3	29
	Hispanic	515	5.4	8.2
	Other races	293	3.1	8.2
	Unreported	2457	25.8	NA

Across all counties in Maryland, the highest and lowest numbers of daily exceedances of ETT_{95} were observed in 2002 and 2009, respectively (Fig. 1A). Likewise, the highest and lowest numbers of daily exceedances of EPT_{90} were observed in 2003 and 2012, respectively. The number of exceedance days for both temperature and precipitation varied across years as well as seasons (Supplemental materials, Fig. S1).

The annual incidence of salmonellosis for Maryland ranged from 12.7 per 100,000 population in 2006 to 17.7 per 100,000 population in 2010 (Fig. 1B). Across all years, we observed a higher incidence of salmonellosis during Summer months followed by Fall, while the lowest incidence was observed during the Winter months (Fig. 1C). While we observed a slight variability in *Salmonella* serotypes recovered from cases across years, the most frequently isolated known serovars included Enteritidis (29.9% of *Salmonella* cases), followed by *Typhimurium* (10.3%), Newport (7.6%), Javiana (4.8%) and serotype I 4,[5],12:i:—(4.7%) (Fig. 1D).

In our overall model, we observed a 4.1% increase in the risk of salmonellosis associated with a 1 unit increase in ETT_{95} exceedance (incidence rate ratio (IRR) 1.041; 95% confidence interval (CI): 1.013–1.069) (Fig. 2, Supplemental materials, Table S1). We then performed restricted analyses for each season (Fall, Winter, Spring, Summer), age group (<5, 5–17, 18–64, ≥65), race (non-Hispanic White, non-Hispanic Black) and geographic area (coastal counties vs non-coastal counties). Based on these analyses, we observed that the salmonellosis risk associated with increases in ETT_{95} exceedance was higher among older age groups and non-Hispanic Whites. The association was positive for Summer while it was negative for the Spring and Winter seasons (i.e. increases in extreme temperature during the Spring and Winter months were protective against salmonellosis) (Fig. 2, Supplemental materials, Table S1). Finally, we observed a 5.1% increase in the risk of salmonellosis (IRR 1.051, 95% CI: 1.023–1.081) associated with a 1 unit increase in ETT_{95} exceedance in the coastal counties, while a 1 unit increase in ETT_{95} exceedance in non-coastal counties contributed to only a 1.5% increase in the risk of salmonellosis (IRR 1.015, 95% CI: 0.977–1.055, Supplemental materials, Table S1).

The findings related to extreme precipitation events were more consistent compared with those related to extreme temperature events (Fig. 2, Supplemental materials, Table S1). In the overall model, we observed a 5.6% increase in the risk of salmonellosis associated with a 1 unit increase in EPT_{90} exceedance (IRR 1.056; 95% CI: 1.035–1.078), but the increase in risk was not equal across all areas. For example, a one unit increase in EPT_{90} exceedance was associated with a 7.1% increase in the risk of salmonellosis in coastal counties (IRR 1.071; 95% CI: 1.044–1.099) compared wtih a 3.6% increase in non-coastal counties (IRR 1.036 95% CI: 1.017–1.054). A restricted analysis based on race

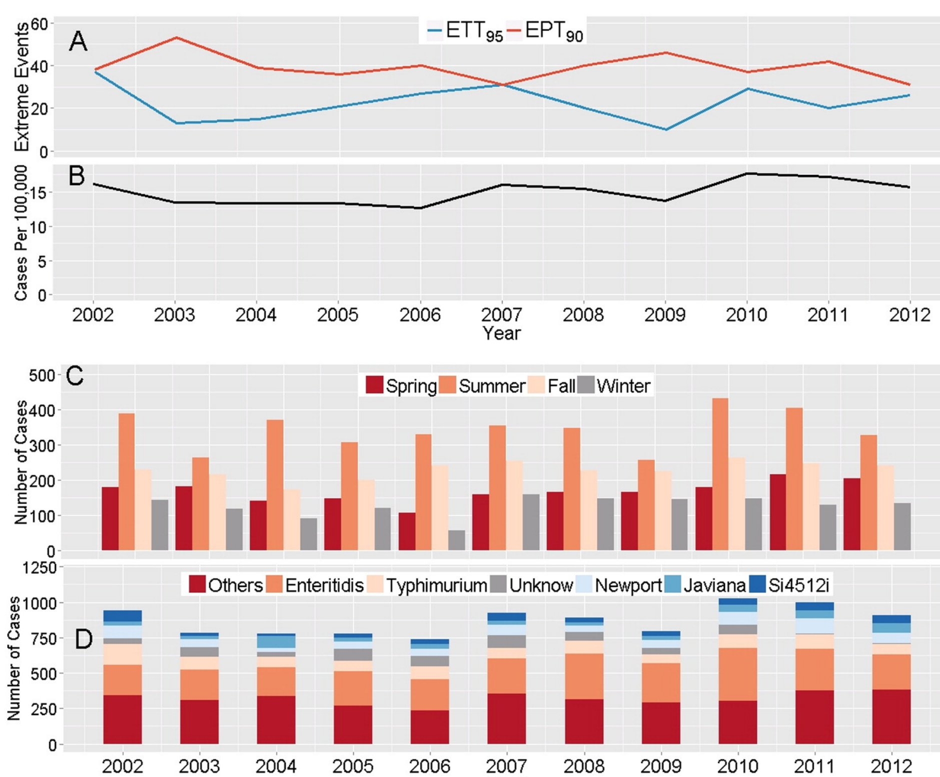

Fig. 1. Temporal trends in extreme temperature and precipitation events (ETT_{95} & EPT_{90}: panel A); incidence of salmonellosis (panel B); seasonal distribution of salmonellosis cases (panel C); and distribution of *Salmonella* serovars recovered from reported cases (panel D) for Maryland, 2002–2012.

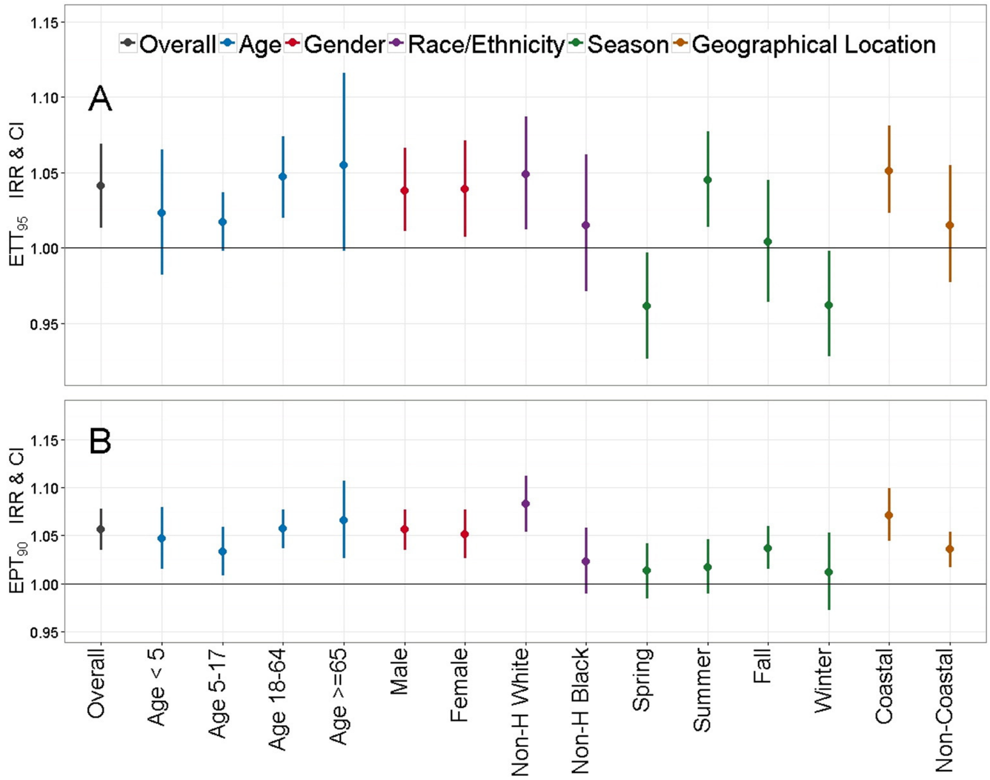

Fig. 2. Incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for exposures to extreme temperature (ETT_{95} exceedance: panel A) and precipitation (EPT_{90} exceedance: panel B) events and the risk of salmonellosis in Maryland separated by age, sex, race, season and geographical location.

showed that the highest precipitation-related salmonellosis risk was among non-Hispanic Whites (IRR 1.083; 95% CI: 1.054–1.112) compared with non-Hispanic Blacks (IRR1.023, 95% CI: 0.989–1.058) (Fig. 2, Supplemental materials, Table S1).

4. Discussion

Our findings suggest that extreme temperature and precipitation events are associated with salmonellosis. Previous studies have shown that the frequency and intensity of such extreme events are increasing and will continue to do so in the coming decades as a result of our changing climate (IPCC, 2013). Our data provide evidence that this will have a direct impact on the overall burden of infectious diseases such as salmonellosis. These findings further highlight the need to engage public health practitioners to prepare for, and respond to climate change associated adverse health effects at local, state, and national levels.

Our study also provides evidence that extreme temperature and precipitation event-related increases in the risk of *Salmonella* infections is more pronounced in coastal communities. One potential explanation for the higher impacts in coastal communities is that temperature and precipitation exceedance events may be more intense (i.e. higher temperatures and heavier rainfall) in these areas. However, since we focused on the daily exceedance of the thresholds (i.e. dichotomous values) as opposed to the actual propensity of increases over the threshold values, we were unable to evaluate this issue directly.

Previous studies have shown that coastal areas are highly susceptible to the impacts of extreme precipitation events, particularly those involving flooding (Moser et al., 2012; Semenza et al., 2012). Flooding events can result in the contamination of drinking water wells and recreational surface water with bacterial pathogens, including *Salmonella* (Simental and Martinez-Urtaza, 2008), that may originate from wastewater treatment plants, private septic systems and animal feeding operations (Semenza et al., 2012). Exposures to contaminated well and recreational water may be more frequent among individuals living in coastal counties in Maryland and other similar geographic areas because 1) there is a higher proportion of people depending on well water in these areas; and 2) these individuals may have contact with nearby recreational waters more frequently than those living inland.

More intense temperature extremes in coastal areas could result in more cases of salmonellosis by providing warmer ecological niches conducive to greater bacterial amplification. In Maryland, this temperature-related amplification of *Salmonella* could be occurring in food, water and other environmental sources of exposure. Maryland produces over 300 million broiler chickens annually on its coastal Eastern Shore (National Agricultural Statistics Service, US Department of Agriculture, 2014). Climate change-related warming could perpetuate the colonization and growth of *Salmonella* in broiler flocks leading to higher contamination levels in consumed poultry products, as well as the waste emitted from broiler operations which could subsequently contaminate nearby water supplies and soil after land application events (Burkholder et al., 2008; You et al., 2006). You et al. (2006) showed that *Salmonella* can persist up to 405 days in soil after manure is applied to a field—a common practice in the broiler chicken-dense region of Maryland's coastal Eastern Shore. Others have suggested that extreme temperature days could indirectly impact the risk of *Salmonella* infections by altering one's eating habits (i.e. individuals consuming more improperly cooked barbeque foods during warmer days) (Kovats et al., 2004).

There are several strengths of our study. The exposure metrics that we used were derived using three decades (1960–1989) of baseline data and the metrics themselves were specific to each county and calendar day. Our outcome measures also encompassed a relatively long duration (2002–2012) that included considerable variability in both the exposure and the outcome measures. We performed stratified analysis to show the differential burden of such extreme events on coastal communities. Our limitations include a relatively small geographic area (24 counties in Maryland). Our findings related to coastal vs non-coastal areas should be interpreted judiciously and replicated in other

States. It is possible that the coastal communities in Maryland may be different than other coastal areas in other States because of the presence of CAFOs and a high proportion of the population on well water. In addition, we did not have information related to specific outbreaks that might have contributed to the temporal clustering of the cases.

Regardless of the specific mechanisms responsible for climate change-related increases in the risk of salmonellosis, our data suggest that coastal communities in Maryland are bearing the brunt of the impact. In the U.S., populations in coastline counties have shown a steady growth, increasing by 84% from 1960 to 2008 (Wilson and Fischetti, 2010). In Maryland alone, coastal Eastern Shore populations are predicted to increase by 29% by the year 2040 (Maryland State Data Center, Maryland Department of Planning, 2014). Therefore, an increasingly larger proportion of the population in Maryland and other U.S. coastal states will be more vulnerable with regard to the impacts of climate change on acute gastroenteritis caused by *Salmonella*. Increased cases of salmonellosis are problematic for public health and result in significant health care costs as pointed out by recent studies that ranked salmonellosis as the costliest foodborne illness in the United States with the annual cost ranging from 3.3 to 11.4 billion US dollars (Hoffmann et al., 2012; Scharff, 2012).

5. Conclusions

Our findings suggest that a single day exceedance in ETT_{95} and EPT_{90} increases the risk of salmonellosis in coastal communities by 5% and 7%, respectively. Since the frequency as well as the intensity of such extreme temperature and precipitation events is expected to grow over the coming decades, public health professionals and policymakers—at local and national levels—will need to incorporate these data in the formulation of meaningful adaptation strategies.

Competing financial interests

No conflicts of interest for any of the authors.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2015.06.006.

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