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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).