The relationship between warm season temperatures and heatwaves on the incidence of *Salmonella* and *Campylobacter* cases in Adelaide, South Australia

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Abstract

Background

Salmonella and *Campylobacter* spp. are the most common foodborne disease pathogens reported worldwide. Changes in climate observed through increasing warmer ambient temperature and heatwaves are considered to be contributing factors to the emergence and re-emergence of foodborne diseases. Warmer ambient temperature enhances the survival of pathogens in the environment, leading to increased contamination of food and water directly impacting on human health when resulting in diarrhoeal illness. Indirectly, social and behavioural factors may also have an impact on foodborne disease as a consequence of climate change. Warmer weather may bring about a change in people's eating behaviour, food preferences, and behaviour related to unsafe food practices potentially increasing the risk of foodborne illness. However, evidence concerning the effects of warmer temperature and heatwaves on *Salmonella* and *Campylobacter* infection is still relatively scarce, and little is known about human behaviour related to food safety practices in response to warmer weather.

Aim

This thesis is divided into four studies each with specific aims. In broad terms, these were: study 1) to assess food safety practices, food shopping preferences and eating behaviours of people diagnosed with *Salmonella* or *Campylobacter* infection and resident of South Australia in the warm season months (January to March 2013), and to identify if socioeconomic status is associated with their behaviour and practices; study 2) to examine the relationship between warmer ambient temperature and the incidence of *Salmonella* and serotypes; study 3) to examine the relationship between heatwaves and the incidence of *Salmonella* and serotypes; and study 4) to examine the relationship between warmer

ambient temperature, and heatwaves and the incidence of *Campylobacter* infection in Adelaide, capital city of South Australia from 1990 to 2012. An overall aim was to provide scientific evidence for public health policy making and practical guideline development for foodborne disease control and prevention in the context of climate change.

Methods

Disease notification data for all studies were obtained from the South Australian state's health department notifiable disease surveillance system. Climate data for studies 2 to 4 were sourced from the Bureau of Meteorology.

Logistic regression was the analytic approach used in study 1, a cross-sectional survey using a questionnaire to examine knowledge, behaviour and perceptions related to food safety. In addition, information about behaviour and preferences related to shopping and dining out, consumption of foods on warm days, preferences for receiving food safety information on warm days and perceived probability of heat as a risk factor for infectious gastroenteritis was also collected. Time-series analysis was the overarching framework used in the analyses for studies 2 through 4 to quantify the effects of temperature and heatwaves on *Salmonella* disease notifications (overall and the five common serotypes), and *Campylobacter* disease notifications in the warm season months (October to March). Specific approaches within these studies included Poisson regression analysis with Generalized Estimating Equations and Distributed Lag Non-Linear Models.

Results

In study 1, *Salmonella* and *Campylobacter* cases generally engaged in unsafe personal and food hygiene practices. Participants had poor knowledge of food safety and they were not aware of high-risk foods associated with an increased risk of foodborne illness. Survey responses specifically related to warm weather found that certain food safety practices, and participants' eating behaviours and food preferences were influenced by temperature, but that generally socioeconomic status did not influence food safety practices.

In study 2, daily *Salmonella* notifications were positively associated with temperature, such that cases increased by 1.3% per 1^{o}C rise in temperature in the warm season. However, greater increases in incidence of *Salmonella* notifications were observed among specific serotypes and phage types. A temperature threshold of 38^{o}C was detected at which notifications for certain *Salmonella* phage types increased in Adelaide.

In study 3, heatwave intensity had a significant effect on daily counts of overall salmonellosis with a 34% increase in risk of infection. Specific *Salmonella* serotypes and phage types were sensitive to the effects of heatwaves. Further, the effects of temperature during heatwaves on the number of *Salmonella* cases and serotypes were found at lags of up to 14 days.

In study 4, there was little evidence of an increase in risk of *Campylobacter* cases associated with either temperature or heatwaves in the warm seasons. During a heatwave, *Campylobacter* notifications decreased by 19% within a temperature range of 39-40.9^{o}C.

Conclusion

This thesis presents the first detailed examination of the effects of warm season temperature and heatwaves on *Salmonella* and *Campylobacter* notifications. Furthermore, this is the first research reported to assess the effects of ambient temperature and heatwaves on *Salmonella* serotypes and their phage types. Overall, these findings demonstrate an increased incidence of *Salmonella* notifications in the warm seasons associated with higher temperature, and more pronounced effects during heatwaves. The findings have also highlighted that human behaviour and food safety practices are influenced by temperature in the warm season months.

These results provide important evidence for policy makers and stakeholders to develop and recommend early warning systems about foodborne disease prevention during heatwaves. In addition, the results highlight the need for targeted public health interventions at a household and population-level in raising awareness and providing education about the importance of food safety in warmer weather.

Publications contributing to this thesis

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P. Factors influencing knowledge, food safety practices and food preferences during warm weather of *Salmonella* and *Campylobacter* cases in South Australia. Foodborne Pathogens and Disease. 2017;14(3):125-131.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P. The effect of temperature on different *Salmonella* serotypes during warm seasons in a Mediterranean climate city, Adelaide, Australia. Epidemiology and Infection. 2016;144(6):1231-1240.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P. Heatwaves differentially affect risk of *Salmonella* serotypes. Journal of Infection. 2016;73(3):231-240.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P. The effects of ambient temperature and heatwaves on daily *Campylobacter* cases in Adelaide, Australia, 1990–2012. Epidemiology and Infection. 2017;145(12):2603-2610.

Conference presentations arising from this thesis

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

29th Annual Scientific Conference of the International Society for Environmental Epidemiology: Healthy places, healthy people – where are the connections? Sydney, Australia, September 2017.

Oral presentation: The effect of warm season temperature on *Salmonella* serotypes and phage types.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

20th International Epidemiological Association World Congress of Epidemiology Conference: Global epidemiology in a changing environment: The circumpolar perspective, Anchorage, Alaska, August 2014.

Oral presentation: Food safety during hot weather: knowledge and practices of *Salmonella* and *Campylobacter* cases in South Australia.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

26th Annual Scientific Conference of the International Society for Environmental Epidemiology Conference**:** From Local to Global: Advancing Science for Policy in Environmental Health, Seattle, Washington, August 2014.

Oral presentation: The relationship between heatwaves and the incidence of *Salmonella* infection in a temperate climate.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

National Climate Change Adaptation Research Facility Conference: Climate Adaptation 2013: Knowledge + Partnerships, Sydney, June 2013.

Speed talk and poster presentation: Food safety practices and knowledge during heatwaves: A survey of *Salmonella* and *Campylobacter* cases.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

The University of Adelaide, Faculty of Health Sciences Postgraduate Research Conference, Adelaide, September 2013.

Poster presentation: Food safety knowledge and practices on hot days: Results from a pilot study of *Salmonella* and *Campylobacter* cases.

Milazzo A, Giles LC, Zhang Y, Koehler AP, Hiller J, Bi P.

The University of Adelaide School of Population Health Seminar Series, Adelaide, February 2013.

Oral presentation: The relationship between heatwaves and the incidence of foodborne illness in a temperate city.

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Abbreviations

BOM	Bureau of Meteorology
CDCB	Communicable Disease Control Branch
CI	Confidence Interval
DALY	Disability Adjusted Life Years
(^{o}C)	Degree Celsius
DLNM	Distributed Lag Non-Linear Model
ENSO	El Nino-Southern Oscillation
GEE	Generalized Estimating Equations
GLM	Generalized Linear Model
IPCC	Intergovernmental Panel on Climate Change
IRR	Incidence Rate Ratio
OR	Odds Ratio
NSW	New South Wales
NZ	New Zealand
RR	Relative Risk
SA	South Australia
UK	United Kingdom
USA	United States of America