The Impact of Heat Waves in Rural Southern Ontario on Dairy Cow Mortality and Human Emergency Room Visits

by

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ABSTRACT

THE IMPACT OF HEAT WAVES IN RURAL SOUTHERN ONTARIO IN RURAL SOUTHERN ONTARIO ON DAIRY COW MORTALITY AND HUMAN EMERGENCY ROOM VISITS

Katherine Elizabeth Bishop **Advisor:**
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In Southern Ontario, climate change caused an increase in frequency and intensity of heat waves which can cause heat stress. A heat wave is a 3-day period with temperatures exceeding 32°C daily. Heat stress is a physiological response to environmental heat which can result in discomfort, morbidity and mortality. The level of discomfort caused by heat stress can be estimated by measures known as Heat Stress Indices (HSIs). Maps visualizing the distribution of heat stress in Southern Ontario were produced by geostatistical kriging. Higher levels of heat stress during heat waves were predicted in the south, particularly surrounding major metropolitan areas. Subsequent research utilized these maps to predict the HSI at point locations. Using Quasi-likelihood Poisson regression, it was estimated that a 1.03 ($p<0.001$) times higher on-farm dairy cow mortality rate occurs for every one unit increase in HSI. Using Poisson regression, it was estimated that rural hospitals have 1.11 ($p<0.001$) times higher admissions during a heat wave than control period. These findings will improve policy for heat wave preparedness in rural Southern Ontario.

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TABLE OF CONTENTS

CHAPTER TWO:

MAPPING DAIRY COW HEAT STRESS IN SOUTHERN ONTARIO – A COMMON GEOGRAPHIC PATTERN FROM 2010-2012

CHAPTER THREE:

DAIRY COW MORTALITY DURING HEAT WAVES AND CONTROL PERIODS IN RURAL SOUTHERN ONTARIO

CHAPTER FOUR:

HEAT STRESS RELATED EMERGENCY ROOM VISITS IN RURAL SOUTHERN ONTARIO DURING HEAT WAVES

CHAPTER FIVE:

DISCUSSION, LIMITATIONS, FUTURE DIRECTIONS AND CONCLUSIONS

APPENDICES:

LIST OF FIGURES

LIST OF TABLES

LIST OF ABREVIATIONS

AIC	Akaike Information Criterion
BLUP	Best Linear Unbiased Predictor
DFO	Dairy Farmers of Ontario
DHI	Dairy Herd Improvement
GLMM	Generalized Linear Mixed Models
GPS	Global Positioning System
GTA	Greater Toronto Area
HSI	Heat Stress Index
IDW	Inverse Distance Weighting
IPCC	Intergovernmental Panel on Climate Change
IRR	Incidence Rate Ratio
Km	Kilometres
KTT	Knowledge Transfer and Translation
L	Litres
LST	Land Surface Temperature
NCDIA	National Climate Data Information Archive
OR	Odds Ratio
RR	Relative Risk
UHI	Urban Heat Island
UTM	Universal Transverse Mercator

LIST OF APPENDICES

STATEMENT OF WORK

Study Design:

I was assisted by Drs. Olaf Berke, David Pearl and David Kelton in designing of the mapping and dairy cow mortality studies. I designed the study of human emergency room visits. I assisted with the letter of intent and application for funding process to the Ontario Veterinary College (OVC) Fellowship and other agencies.

Data Collection:

Chapter 2: I completed the grey literature search for possible heat wave dates and extracted the data from Environment Canada's National Climate Data and Information Archive (NCDIA).

Chapter 3: Dr. Karen Hand collected dairy cow mortality data for a specified series of dates from the CanWest Dairy Herd Improvement (DHI) database.

Chapter 4: I collected population data from Statistics Canada to determine which hospitals were rural from a list of all Ontario hospitals obtained from the Ontario Hospital Association (OHA). I collected data on emergency room visits from 24 hospitals.

Data Analysis:

I analyzed the data collected for each study with the assistance of Drs. Olaf Berke, David Pearl and David Kelton. Bimal Chhetri assisted with the geographic boundary files and projection of coordinates to Universal Transverse Mercator (UTM).

Results Sharing:

I prepared the manuscript for each of the research chapters and the literature review and discussion before receiving edits from Drs. Olaf Berke, David Pearl and David Kelton. I was responsible for making the appropriate changes to the manuscript following editing.

I presented the research at a variety of conferences in both oral and poster format including OVC Graduate Symposium, OMAF and MRA Emergency Management Research Expo, Global Development Symposium, Conference for Research Workers in Animal Diseases (CRAWD) and others. Olaf Berke presented the research at the Canadian Association of Veterinary Epidemiology and Preventative Medicine (CAVEPM) conference.

CHAPTER 1:

Introduction, Literature Review, Methodology, Information Sources and Objectives

INTRODUCTION

In Southern Ontario, the trends of climate change have led to substantial changes in the summer seasons including, but not limited to, heat waves. A heat wave is a period of continued and high temperatures, although the exact definition varies. Heat waves have substantial impacts on human and animal health alike, and have the potential to cause heat stress. Heat stress is a physiological response to extreme heat which causes discomfort, illness and sometimes results in death. While heat stress studies have been done around the world, and the physiological impacts of heat stress are well understood at the individual level, there is little known about the impact that heat stress has on the communities of Southern Ontario. The goal of this research project was to map the distribution of heat stress across the region of Southern Ontario and to use these maps to identify areas of high risk for heat related mortality in dairy cattle and morbidity in humans, respectively, as well as determine the impact increased heat stress had on the rate of these events.

A heat wave is an ambiguous term intended to refer to a period of prolonged heat stress in a region. Definitions for a heat wave can vary by the minimum length of time, the measure of temperature considered (for example, daily maximum or minimum temperature), or the inclusion of additional variables such as humidity or wind speed. Some such definitions include 5 consecutive days or longer which exceed the average historical maximum temperature by 5 ˚C or more (Frich et al. 2002), a period of undefined length which is abnormally and uncomfortably hot and humid (Glickman 2000), a period of 3 or more consecutive days for which the daily maximum temperature in the shade exceeds 32.2 ˚C (i.e. 90 ˚F; Burrows 1900), or a period of unusual warmth for a region which is not explicitly defined (Robinson 2001). For this study, a heat wave is defined as 3 or more consecutive days of maximum daily temperatures which exceed 32.0 ˚C, in accordance with the definition used by Environment Canada (Environment Canada 2013). Due to the size of the current study area (i.e. Southern Ontario), the heat wave definition is extended by the condition that weather stations from at least 3 counties fulfil the Environment Canada definition simultaneously.

Heat stress is the physiological response to environmental heat exposure which can occur in humans as well as many other species such as dairy cattle or plants. In humans, this response is characterized by illness which may include nausea, dehydration, exhaustion, elevated body temperature, sweating, flushed skin and/or confusion (Ontario 2013). Heat stress is an encompassing term which includes heat exhaustion, heat stroke and heat related illness. Heat stress was studied for this project rather than the more limiting definitions of heat exhaustion or heat stroke to illustrate the broader impacts of heat waves on Southern Ontario and to create a more general image of heat-related illness in the region. This information will be invaluable to dairy farmers and public health units of Ontario in preparation for future heat waves and in the decision making process for emergency preparedness.

The following literature review discusses the impacts of heat waves on livestock and human health and the epidemiology of heat stress which justify the need for this research. Background is provided about heat stress indicators which will be used throughout the project to evaluate heat waves. The literature review discusses the future of heat waves and heat stress in a Canadian and global context and the role this research may play in the future. Finally, methods and data sources are described in this chapter.

LITERATURE REVIEW

Impacts of heat waves on livestock health

As with humans, livestock species such as cows (Vitali et al. 2009; Bernabucci et al. 2014), pigs (D'Allaire et al. 1997) and chickens (St-Pierre et al. 2003; Quinteiro-Filho et al. 2012) can experience heat stress. Similar to the physiological response in humans, livestock can experience heat stress morbidity and heat stress related mortality (Nardone et al. 2010).

In dairy cattle specifically, regional thresholds have been estimated, over which mortality is expected to increase. In Italy, researchers established a threshold for increased dairy cow mortality above a Heat Stress Index (HSI) of 70 units (Vitali et al. 2009), and an odds ratio (OR) of 1.6 for mortality above the threshold (Crescio et al. 2010).

Collier et al. (2006) attribute the increases in dairy cow heat stress in recent years to changes in production, not only the environment; rather, it has been suggested that with dramatic increases in production, the metabolic output of the cow puts her at increased risk and susceptibility for heat related illness. Productivity losses associated with heat stress include decreased performance (feed intake, growth, milk production), increased mortality and reduced reproductive success (St-Pierre et al. 2003; Nardone et al. 2010). Each dairy cow currently lactating is estimated to produce 1.5-2.0 liters less milk per day during a heat wave (Reiczigel et al. 2009). In Italy, it was estimated that decreased dairy production may begin at an HSI as low as 65 units (Bernabucci et al. 2014). The likelihood of a successful insemination during extreme heat stress decreases dramatically (Wilson et al. 1998; Badinga et al. 1993), and the rate of survival of new calves born during a heat wave is substantially lower (Martin et al. 1975). St-Pierre et al. (2003) estimate that the economic losses due to heat stress in the contiguous United States livestock sector amount to $1.7 billion, of which about half is attributed to the dairy cow industry.

The use of heat abatement strategies can have a dramatic impact on dairy cow welfare and survival (Collier et al. 2006). For the United States, St-Pierre et al. (2003) predicted a reduction in productivity losses of more than 25% when heat abatement strategies are used intensively rather than minimally. Other tools suggested to be helpful in reducing the impact of heat waves on dairy cow survival include direct cooling, nutritional changes, and breeding techniques (Gauly et al. 2013).

These production losses and increases in mortality have impacts far beyond economics; the welfare of these animals is also negatively impacted (Phillips 2002). It is known that cold temperatures rarely stress cattle since the lower threshold for dairy cattle discomfort is -23 ˚C (Beaverlin et al. 1989). In contrast, physiological heat stress responses in dairy cattle are recorded to begin as low as 21 ˚C, and increase substantially at 25 ˚C (Phillips 2002). Heat stress as measured by the HSI is associated with increased dairy cow mortality at a level of 70 units (Vitali et al. 2009). Holstein-Friesian cattle are the most susceptible breed to heat stress, dramatically contrasted to cattle evolved in warmer climates (Jan and Nichelmann 1993). In Ontario 94% of dairy cows are Holstein-Friesians (Dairy Farmers of Ontario, 2012). Dairy cattle are slowly adaptable to changes in climate. A dairy cow is able to withstand the slow seasonal changes of life in a temperate climate such as Southern Ontario; however, they are unable to cope with the steep increases in temperature associated with heat waves (Vitali et al. 2009).

There is a clear indication of the negative impact which heat stress can have on dairy cows. It is therefore important to understand the impact that future heat waves will have on dairy cows in Southern Ontario and their caretakers (i.e. farmers).

Impacts of heat waves on human health

With environmental heat, there is a risk of heat stress for an individual. Therefore, with increased risk of extreme heat and heat related events in the future (Meehl and Tebaldi 2004) there is increased risk of heat related illness and heat stress in the population (Peng et al. 2011). Research regarding the impact of past heat waves on human health suggests that specific ailments such as stroke (Ha et al. 2013), dehydration, hyperthermia, malaise, hyponatremia, renal colic and renal failure increase during heat wave events (Josseran et al. 2009). Temperature health relationships are most extreme when they are in contrast to the norm. In Canada, the impacts of extremely hot temperatures are more substantial than extremely cold temperatures as a result of natural adaptations (Curriero et al. 2002). North American and European studies of heat waves indicate that there is an association with increased mortality during extreme heat (Whitman et al. 1997; Rocklov et al. 2012; Son et al. 2012; Laaidi et al. 2012). In the Eastern United States, recent climate change scenarios project that by the year 2057, excess mortality due to heat waves will be at a level of 200-7,807 deaths per year (Wu et al. 2013). Associations between heat and mortality are particularly noticeable in the elderly (Kim et al. 2012) and in women (Diaz et al. 2002). Among other vulnerable groups inner city urban areas (Kim et al.

2012) and rural communities (Martinez Navarro et al. 2004) are recognized as being disproportionately affected by heat related illness. These social inequities can be seen not only in developing countries, but are a problem for developed countries too as heat waves increase in intensity (Haines et al. 2006). However, although research indicates both urban and rural areas are disproportionately affected by heat stress in contrast to suburban areas, research is primarily available to illustrate the extent of the problem in major cities such as Toronto (Kershaw and Millward 2012; Bassil et al. 2009; Pengelly et al. 2007; Smoyer-Tomic and Rainham 2001), Montreal (Price et al. 2013), Chicago (Whitman et al. 1997), and Baltimore (Huang et al. 2011). Moreover, heat stress is a known workplace hazard for those working outdoors during the summer (Gubernot et al. 2013), which includes a substantial portion of the rural population of Southern Ontario. For example, in Ontario between the years 2004 - 2010, 785 heat related illness events resulting in lost time claims were reported as a result of occupational heat illness (Fortune et al. 2013). This indicates a gap in knowledge for what the impacts of heat waves are on rural communities in Canada.

Understanding how heat waves affect rural Canadian communities, such as those of Southern Ontario will aid in making informed policy decisions such as allocation of provincial and federal level resources or the implementation of surveillance systems or cooling centre facilities. In the past, heat waves were fewer and farther between. In the last 50 years in Southern Ontario, the only heat waves documented occurred since 2003, and since 2003, a heat wave has been recorded at least once every summer (Environment Canada 2013). Since heat waves were relatively rare in the past, policy makers often neglected the impacts of heat waves as a one-time disaster, leaving the following government to deal with the problem as if it were new yet again

(Allexenberg 1981). More recently, heat wave preparedness is receiving increased attention (Government of Canada 2013).

The population health perspective of heat stress

The objectives of epidemiology are to (i) identify the etiology of a disease and relevant risk factors, (ii) determine the extent of disease and its distribution, (iii) determine the natural history of disease and future prognosis, (iv) evaluate the potential for treatments and therapeutics and (v) establish a foundation for public policy related to health or disease (Gordis 2009). The importance of epidemiology in veterinary medicine is highlighted in the literature, and suggests that epidemiology strives to optimize production and limit disease to promote animal health, welfare, productivity and profitability (Kelton 2006).

Heat stress is a population level problem for dairy farming as it will affect entire populations of dairy cattle across regions such as Southern Ontario as heat waves become more frequent and intense. Similar effects result from heat stress in human and animal populations. Heat stress can cause both morbidity and mortality in these populations. Understanding the impacts of disease on the population paves a way for epidemiologists to impact lifesaving policy related to heat abatement and resource allocation, including heat stress.

In recent years, the One Health concept (Shomaker et al. 2013) has been emphasized as a necessary step to combat health issues which affect humans, animals, and the environment (Currier and Steele 2011). Shomaker et al. (2013) illustrate the interdisciplinarity and breadth of One Health when they suggest the involvement of researchers from areas such as agriculture, animal science, environmental science, climatology, veterinary medicine, human medicine and public health can all benefit from the One Health perspective. Some epidemiologists have been using the One Health approach for decades. This is illustrated by the coining of the term One Medicine, the precedent of One Health, by a renowned epidemiologist, Dr. Calvin Schwabe, in his book *Veterinary Medicine and Human Health* (Schwabe 1964). This has local significance as Dr. Calvin Schwabe was adviser and mentor to Drs. Wayne Martin and David Waltner-Toewes who previously taught in the Department of Population Medicine at the University of Guelph. It has been suggested that climate change is the most pressing environmental health issue of the present and future, with the potential for dramatic increases in temperature around the world, increases in extreme weather events and population displacement, all of which may have fatal consequences (Shomaker et al. 2013). Moreover, climate change is a recognized threat for not only humans, but domestic and wild animals, as well as plants. Researchers believe that a One Health approach to medicine in the future is the most effective way to mitigate the harmful impacts of climate change on health (Shomaker et al. 2013).

Heat stress indices (HSIs)

A variety of measures, known as heat stress indicators (HSIs) are available to estimate the level of heat stress associated discomfort an individual feels, accounting for temperature and humidity and some other optional parameters (Barnett et al. 2010). An HSI may be calculated using dry bulb temperature (Johnson and Vanjonack 1976), dew point temperature (Johnson and Vanjonack 1976), wet bulb temperature (Ingram 1965) and / or relative humidity (National Weather Service 2013) and may be adjusted for parameters such as wind speed or solar radiation (Patel et al. 2013). In a comparison of five HSI estimators in 105 cities, Barnett et al. (2010)

demonstrated that when used appropriately, all HSI estimators are equally predictive of heat stress in the environment. As a result, the best HSI for a new study is the index with the least missing data (Barnett et al. 2010).

For work in rural areas or large land areas, it has been shown that an HSI is a better estimator of ground level heat stress when based on weather station data rather than satellite imaging (Maloley 2009). Satellite imaging for heat stress has two major flaws. The first problem with satellite imaging is that measurements are taken daily rather than hourly and can miss the time of day of most extreme (i.e. maximum or minimum) heat stress in the region (Wilhelmi et al. 2004), thus making it a proxy for heat stress in the area, unable to estimate the range of daily heat stress. The second problem with satellite data is that they measure land surface temperature (LST) rather than air temperature. Air temperature in rural areas has been shown to more strongly correlate with the true temperature than the estimated LST (Wilhelmi et al. 2004).

Temperature thresholds (i.e. categorical indicators) have also been shown to be less effective at estimating local heat stress than an HSI (i.e. continuous measures). In Chicago, the HSI better predicted an increase in emergency room visits and 9-1-1 emergency calls than temperature alone (Hartz et al. 2012). In Spain, the use of temperature thresholds has proven somewhat unreliable as a predictor for mortality, indicating the difficulty in identifying an appropriate threshold for increased risks (Tobias et al. 2012). In contrast, Korean researchers found temperature to be a better predictor of heat related illness than an HSI (Na et al. 2013); however, the threshold established (i.e. 32.2 ˚C) was similar to the definition of a heat wave in Canada (i.e. 32.0 ˚C; Environment Canada 2013). Unlike temperature thresholds, HSI thresholds have been proven to be effective predictors of morbidity and mortality (Vitali et al. 2009).

Future of heat waves and heat stress

It is now commonly accepted, that the frequency, intensity and duration of heat waves are inevitably increasing as climate change progresses (Meehl and Tebaldi 2004; Wilhelmi 2004; McMichael et al. 2006; Haines et al. 2006). It is estimated by the Intergovernmental Panel on Climate Change (IPCC) that the average temperature around the world will increase by 1.4 - 5.8 ˚C by the year 2100 (IPCC 2001). More importantly, climate change is of great concern because of the extreme variations in temperature such as heat waves and cold spells. Although many models exist for the future impacts of climate change on global temperature, the directionality predicted by models unanimously is increasing (McMichael et al. 2006; Tebaldi et al. 2006). Moreover, the impact of these changes for Canada and other countries of high latitudes are projected to be at a higher magnitude than those countries closer to the equator (IPCC 2001). Climate change is now so far progressed, that climatologists predict that even with a halt on greenhouse gas emissions the impacts of climate change will be increasing and felt for at least several decades (IPCC 2001). Beyond the predicted increases in average annual temperature is the prediction that increases in extreme weather events will accompany this climate change. The IPCC predicts increased variability in temperatures and more record high and low temperatures (IPCC 2001) which can make it more difficult for the body to acclimate to environmental temperature (Vitali et al. 2009). Heat waves are included in the long list of extreme weather events likely to occur more frequently in the future (Houghton 2004).

As heat waves become an increasing problem in the future, undoubtedly the health impacts of heat stress will increase as well. Predictions by the IPCC (2001) suggest that extreme weather events such as heat waves pose the most threat to public health. It is suggested that human populations will adapt to changes in climate through physiological, technological, behavioural and cultural shifts, however the impact of an extreme heat wave may still be too much for most populations (McMichael et al. 2011). Research has previously shown that mortality rates increase when temperatures exceed a particular comfort threshold in a region (Curriero et al. 2002); however, as a result of the adaptations alluded to by the IPCC this threshold is variable by country or region.

EPIDMIOLOGICAL AND STATISTICAL METHODOLOGIES

Kriging

Kriging is a geostatistical method for predicting values within a study area based on observed point measurement data and weightings of distance and dependence structure where the closest points have the greatest impact on the predicted value (Cressie 1993). Kriging is based on the fundamental law of geography, commonly known as Tobler's Law. Tobler's Law states that, "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970). Kriging is also based on the stationarity assumption, that there is homogenous variation in the phenomenon (i.e., weather) across the study area represented by spatially constant means and variances (Oliver and Webster 2007). Kriging is a prediction technique, which relies on the concept of best linear unbiased predictors (BLUPs). When data from an irregular net of observation locations (e.g. weather stations) are predicted by kriging to a regular grid of prediction locations the phenomenon under study can be visualized by isopleth mapping. An isopleth map is a depiction of a third dimension on a map, often by colour or intensity of a z-value at a location (x,y); Pardhan-Ali et al. (2012) provide an example of the relative risk of notifiable gastrointestinal illness in the Northwest Territories.

Kriging is an interpolation method that is particularly useful because of its predictive abilities (Cressie 1989). Kriging is a geostatistical interpolation method which contrasts it from mathematical or deterministic interpolation methods such as inverse distance weighting (IDW) and spline interpolation. IDW is one of the most commonly used deterministic models for spatial interpolation because it is relatively fast and easy to calculate (Lu and Wong 2008), however IDW can be biased by the presence of localized clusters of observation locations which can impact the accuracy of the results (Pfeiffer et al. 2008). Spline interpolation is a complex mathematical interpolation method which uses a piecewise polynomial function known as a spline to predict values between points (Yu 2001). In contrast, geostatistical kriging predicts values based on statistical models which include measures of autocorrelation (Cressie 1993). To do this, kriging is based on the assumption that the spatial correlation structure is stationary, (i.e. constant across the study area; Bailey and Gatrell 1995), which the user must then verify. Kriging is commonly used to predict geographical measures such as soil or air concentrations of minerals or contaminants, and was originally developed for mining and meteorology, but was underused for health status data analysis until recently (Gotway and Wolfinger 2003). As a result of including these measures of autocorrelation in geostatistical models, kriging can produce both a predicted value and an estimate of the precision of these values. This precision or accuracy measure, the mean squared prediction error, is akin to measures of variance, and can be mapped too.

Kriging is not an automatic process; rather, kriging requires an interactive approach to produce predictive maps. The interactive process for kriging is a multi-step evaluation of the data, variance, relationship between points and the surface for which the prediction is intended.

Kriging often uses (semi-) variograms to model the autocorrelation or spatial dependence (Berke 1999).

A number of semivariogram models exist. Semivariograms may be spherical, exponential, Gaussian or linear, each with a variety of strengths and weaknesses and outlined by Bailey and Gatrell (1995). Briefly, the 2 most commonly used semivariograms are spherical and exponential. The spherical semivariogram structure shows a progressive decrease of spatial autocorrelation until a point where the correlation reaches zero. The exponential semivariogram model shows decreases in correlation with increased distance but the correlation never reaches zero (Bailey and Gatrell 1995). Weather is a phenomenon best fit using the exponential model since weather systems are so large that distance does not make events truly independent. The decision for which model to use should always be based on prior knowledge of the phenomenon (Bailey and Gatrell 1995).

For this project semivariograms were fit using the weighted least squares method. The point on the y-axis where the curve begins (akin to the intercept) is the nugget, a point which indicates the uncorrelated variation in the data (Pfeiffer et al. 2008). The nugget parameter refers to the variance in measurement errors of data, or “noise” (van Beers and Kleijnen 2003). As weather recording instruments in 2010, and later, are considered to have negligible if any measurement error, the nugget effect throughout this project was set to zero. The point at which a semivariogram curve begins to flatten is known as the sill and represents the maximum semi-variance in the data (Pfeiffer et al. 2008). The distance or lag along the x-axis corresponding to the sill of the curve is known as the range (Pfeiffer et al. 2008). The semi-variance should be estimated to a maximum distance of no more than half the distance between the two farthest separated points (Waller and Gotway 2004). In this case the weather stations in Windsor and in

Ottawa are the furthest separated. A maximum distance of half the largest separation is generally needed to determine stationarity of the mean and is also done because there are generally too few points for sufficient sample size at longer distances. A steeper semivariogram function indicates the increased influence of local measurements compared to distant measurements. An illustration of a labeled semivariogram is provided in Figure 1.1.

Three main kriging methods exist: simple kriging, ordinary kriging and universal kriging. Ordinary kriging is the most widely used kriging method, and it assumes that the constant mean is unknown (Cressie 1993). Ordinary kriging is an extension of simple kriging, which assumes that the trend is known. In contrast, universal kriging is used to illustrate the impact of an overriding trend in the data but which is not known (Bailey and Gatrell 1995). Universal kriging is commonly used in combination with deterministic methods, and should only be used when there is a justifiable trend in the data for which universal kriging will be a better descriptor (Cressie 1993). For these reasons, in this project ordinary kriging rather than universal kriging was applied.

Kriging will be used in Chapter 2 to produce heat stress maps of Southern Ontario during three heat waves from 2010-2012 and six control periods over the same time frame.

Poisson Regression

Poisson regression models are used primarily to model count data (Dohoo et al. 2009). Types of counts which can be modelled using a Poisson regression include: simple counts, counts over time (time at risk), counts per population unit or counts per spatial unit (Dohoo et al. 2009). When a Poisson regression is used to investigate the occurrence of an event over time the result is a rate over time with respect to a change in the covariate pattern (Petrie and Watson 2006). Poisson regression models are primarily used to model events considered to be rare.

Spatially correlated data can have the same impact on Poisson regression models as working with clustered data (Pfeiffer et al. 2008). This can be detected by overdispersion in the model. Special Poisson models have been developed for working with spatially correlated data to eliminate problems with over- and under-dispersion. Here quasi-likelihood estimation is applied to fit a spatial Poisson regression model to the data in place of traditional maximum likelihood estimation. These models can be employed in various general purpose software programs including R (R Development Core Team 2013). A spatially correlated Poisson model can be used to estimate the range of spatial dependence among others. It is noteworthy that data may be spatially correlated (represented by the range), without having a spatial trend. As a result of using Quasi-likelihood estimation the Akaike Information Criterion (AIC) cannot be calculated. In place of the AIC, the quasi-AIC and other diagnostics such as a quantile-quantile (Q-Q) plot of residuals and a plot of the predicted against observed incidence are used. A well-fitting Poisson regression will generate or result in a Q-Q plot of Anscombe residuals with a Gaussian distribution and the predicted versus observed incidence plot should produce a straight line. A Q-Q plot of residuals is sufficient to identify gross errors in the fit of the model except in the presence of outliers.

Poisson regression will be used in Chapter 3 to compare the rate of on farm dairy cow mortality during heat waves to control periods from 2010-2012. And later in Chapter 4, Poisson regression will be used to compare the rate of emergency room visits during heat wave and control periods in rural hospitals from 2010-2012.

Spatial Scan Test

The spatial scan statistic was developed to detect and evaluate the significance of clusters of point data such as disease counts with a window of variable size, shape and position (Kulldorff 1997). A spatial scan statistic for rare events or count data based on the Poisson distribution was developed by Kulldorff (1997). The scan statistic moves over a study region in varying overlapping circles to identify the probability of disease or event within the circle (p) in comparison to the probability outside of the circle (q). The scan statistic uses a variable window size to capture any possible cluster within the region. In order to adjust for multiple testing issues, the p-value obtained by the spatial scan statistic is adjusted to account for the number of trials (Kulldorff et al. 2007). A cluster is identified if the area within the circle has $p>q$ where p is in the top 2.5% of observations (i.e. a high risk cluster) or if the area within the circle has $p<q$ where p is in the bottom 2.5% of observations (i.e. a low risk cluster; 2-sided test; Kulldorff 1997). In dealing with heat stress, there is interest in both high and low-risk areas. The Poisson Distribution Scan Test is described by Kulldorff (1997). Using this method, the spatial scan statistic identifies high and low risk areas under the assumption that the entire region experiences an event only rarely. This model is able to accommodate rare events as is the case for mortality on farm or visits to the emergency room. According to Lawson and Kleinman (2005), it is appropriate to use the Poisson Scan Test when there is a population on mass at risk and the distribution of cases is likely to follow a Poisson distribution. The Poisson distribution spatial scan statistic usually uses aggregate populations within political boundaries (Lawson and Kleinman 2005) as will be done for the emergency room data. A similar outcome can be achieved using the total number of cows on farm. The spatial scan statistic is accomplished by using a Monte Carlo hypothesis testing procedure. A default of 999 Monte Carlo permutations is

used in order to obtain p-values with a finite number of decimals. Spatial scan tests exists for investigation of non-circular clusters using the Poisson distribution (e.g. Tango and Takahashi, 2005); however there is no evidence for what may cause a non-circular cluster in applications considered in this research project and thus its use is not entirely justified.

DATA AND INFORMATION

Sources of information

Environment Canada

The Environment Canada National Climate Data and Information Archive (NCDIA; Environment Canada 2013) is a national Canadian Government hosted website and database maintaining weather data and definitions of climate related terms for use by the public. The NCDIA provides information from weather stations which record on a variety of intervals including hourly, daily, and monthly. Weather records as far back as the year 1840 are available and publicly accessible via the internet.

Each weather station in the system is given a "Climate ID", and the exact latitude and longitude are provided in minutes and seconds. Elevation is also recorded for each weather station. Hourly weather stations were used for the production of heat stress maps to ensure the inclusion of the true daily maximum heat stress value. Variables collected at weather stations that report hourly include: dry temperature, dew point temperature, relative humidity, wind direction, wind speed, visibility, pressure reading, Humidex, wind chill and weather description (i.e. "Partly cloudy"). In total, hourly records from 37 weather stations were available for

Southern Ontario from 2010-2012 and 92 weather stations recorded only daily observations in the same region during the same time frame (Environment Canada 2013).

CanWest Dairy Herd Improvement and Dairy Farmers of Ontario

The CanWest Dairy Herd Improvement (DHI) Program is a non-profit corporation which supports approximately 4,200 dairy herds across Canada in five provinces, including Ontario (CanWest 2013). Established in 2004, CanWest DHI combines the services of the Ontario DHI and the Western Canadian DHI. In 2009, Ontario had 2,898 dairy herds enrolled in CanWest DHI, and only 1,186 were not enrolled (Hand et al. 2012). Of the total 4,084 dairy farms in Ontario, nearly all are located in Southern Ontario. The CanWest DHI offers a variety of health related programs concerning: milk recording, milk component and somatic cell count analysis, Johne's disease, bovine leucosis, mastitis, bovine viral diarrhea and pregnancy testing.

CanWest DHI also ensures up to date and active recording of dairy herds, individual cows and milk. This recording of high quality herd and individual information is essential in tracking mortality during heat waves. Data extracted from the CanWest DHI database were used to ensure the sufficient quality of data for date of death of cows enrolled in the program.

The database belonging to Dairy Farmers of Ontario (DFO) was used in conjunction with the DHI database to ensure accurate and thorough data collection, as well as to increase the number of parameters available for testing. Farms which are enrolled in the CanWest DHI program use a unique herd identification number which is matched to the DFO herd number in the CanWest DHI database. As a result, some additional information is available through the DFO such as the farms exact global positioning system (GPS) location. Farms were included if the herd could be identified in both databases and matched by the herd identification number. A total 94.1% of all death or movement records in the DHI database on the 27 dates of the study period (nine 3-day periods) across Southern Ontario were matched to farms in the DFO database.

Types of data available for proxy measures of morbidity or mortality

Various measures exist as proxy counts for health or disease in a community. These proxy measures are considered substitutes as there is little chance that any measure will entirely capture the picture of health or disease in a population. As a result, there are both pros and cons to choosing a particular estimator for research. In previous heat wave studies, researchers have used 9-1-1 dispatch data (Kershaw and Millward 2012; Williams et al. 2011), emergency room visits (Jones et al. 1982), death records (Martinez-Navarro et al. 2004), surveillance systems (Na et al. 2004; Lowe et al. 2010), or a combination of the above (Schaffer et al. 2012). The use of emergency room visits for this study was chosen as a proxy for morbidity rather than for mortality. Moreover, unspecified emergency room visits were used to capture a more complete image of illness resulting from heat exposure. Heat related emergencies may not be recorded as such if the primary cause for the emergency room visit was for another diagnosis. Research shows that such ailments as stroke are provoked by extreme heat exposure (Ha et al. 2013), and may be missed in an analysis of heat related emergency room admissions. To use records of all hospital admissions, it is important to select unbiased control periods representing a "normal" period of emergency room admissions in the region.

A case-cross over study design has been used in heat stress research previously as a way to evaluate the impact of heat stress on similar communities in repeated sampling frames

(Stafoggia et al. 2008). A case-cross over design with a sufficient wash-out period (in this study 3-weeks) can illustrate the impact of exposure in an observational study where the communities are relatively unchanged in other aspects.

OBJECTIVES

The primary goal of this project was to illustrate the distribution of heat stress across Southern Ontario in the form of a map and to understand the population level health impacts of heat waves for dairy cattle, and humans in rural Ontario. To understand the health impacts of heat waves on dairy cattle, death records were used to determine if there was an increased dairy cow mortality rate during a heat wave. To understand the health impacts of heat waves on humans, emergency room visits were used as a proxy for morbidity during 3 heat waves.

The specific objectives were as follows:

- Map the heat stress index for Southern Ontario for three heat waves and six control periods from 2010 to 2012, and compare the spatial heat stress pattern over time and identify areas of high-risk for heat stress and heat related illness. This objective is addressed in Chapter 2.
- Compare the on farm dairy cow mortality rate during heat waves and control periods using heat stress maps (created in Chapter 2) and identify areas of high risk. This objective is addressed in Chapter 3 using data from CanWest DHI and DFO.
- Use emergency room visit data from rural hospitals in conjunction with heat stress maps (created in Chapter 2) to determine if heat waves increase morbidity in rural communities similarly to the impact that heat waves have in major metropolitan areas. Specifically, the

objectives were to identify the levels of heat stress experienced by rural communities of Southern Ontario during a heat wave, to determine if heat waves had a significant impact on the number of visitors to rural hospital emergency rooms, and to identify areas of high-risk for heat stress related illness in Southern Ontario. This objective is addressed in Chapter 4.

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Figures and Tables

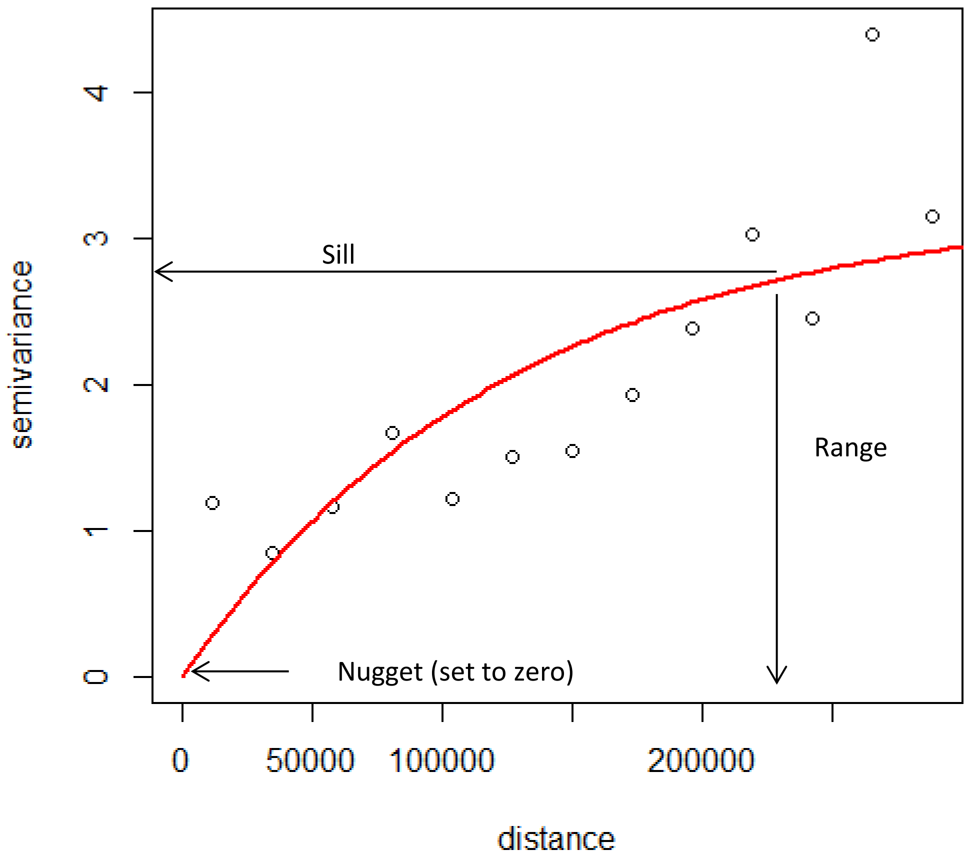

Fig. 1.1- An empirical semivariogram produced for the 2011 heat wave with illustrative labels for the components of a semivariogram (nugget, sill and range).

CHAPTER 2:

Mapping Dairy Cow Heat Stress in Southern Ontario - A Common Geographic Pattern from 2010-2012.

***As submitted to Environmental Monitoring Assessment (April 2014)**

Abstract

In Southern Ontario, climate change has resulted in an increased occurrence of heat waves, causing heat stress among humans and livestock, with potentially fatal consequences. Heat waves are defined as three consecutive days of temperatures greater than or equal to 32°C. Maps visualizing the distribution of heat stress can provide information about related health risks and insight for control strategies.

Weather data were collected from weather stations throughout Southern Ontario for dry bulb temperature and dew point temperature. The Dairy Cow Heat Stress Index (HSI) was estimated by averaging the first three days for three heat waves, during 2010, 2011 and 2012. Geostatistical kriging was used to map three-day averages of maximum heat stress over periods involving a heat wave and control periods three weeks prior to and following heat waves.

Average HSI for each period across Southern Ontario ranged from 55 to 78 during control periods, and from 65 to 84 during heat waves, surpassing levels where mortality is known to increase substantially. Heat stress followed a consistent geographic pattern with the most affected areas in the southern region of the study area, surrounding major metropolitan areas.

These HSI maps indicate areas which are less optimal for dairy farming within the study boundary. Thus, some areas currently used for dairy farming and at high-risk for heat stress mortality may require heat abatement strategies to sustain dairy cow production as heat waves become more frequent and intense due to climate change.

Keywords:

Heat stress, heat wave, kriging, Southern Ontario, dairy cows

1. Introduction

Heat waves are defined by Environment Canada as three or more consecutive days of temperatures of at least 32°C (Environment Canada, 2013). Heat waves can cause heat stress in humans and in animals, and result in heat related fatalities. Numerous studies have considered the impacts of heat waves on human health and found that heat waves can cause increased mortality, particularly in vulnerable populations (Wilhelmi et al. 2004). Heat stress has also been shown to increase mortality in dairy cows (Vitali et al. 2009) and pigs (D'Allaire et al. 2009). Over the next century, heat waves are expected to increase in both frequency and intensity (Meehl and Tebaldi 2004; Wilhelmi et al. 2004), increasing the public and animal health problems associated with extreme heat. Like humans, dairy cows are at risk of experiencing increased morbidity and mortality due to heat stress during heat waves, as well as experiencing substantial losses in milk production. Dairy cows, although adaptable to shifts in weather and climate, do not respond well to rapid increases in temperature or prolonged periods of extreme heat (Martin et al. 1975; Vitali et al. 2009). Increased mortality in dairy cows during the summer months has been reported in California (Martin et al. 1975), Italy (Vitali et al. 2009) and Hungary (Solymosi et al. 2010).

Population heat stress studies have been conducted in urban centres including Toronto (Kershaw and Millward 2012; Bassil et al. 2009), Chicago (Whitman et al. 1997), Rennes (Buscail et al. 2012) and Athens (Keramitsoglou et al. 2012). While these studies have demonstrated the variability in heat stress over short distances, little has been done to study regions with a combination of rural and urban areas. Urban heat islands (UHIs) are recognized factors for warming effects in major metropolitan areas and thus are the central focus of current research (Buscail et al. 2012). However, heat stress mapping to show the progression between urban areas and rural areas can improve heat stress preparedness. Moreover, this project aims to better understand heat stress in rural Southern Ontario as it relates to human and animal health which currently has not been well studied.

With increasing frequency and intensity of heat waves, comes increased public health burden (Meehl and Tibaldi 2004). Pengelly et al. (2007), found that on average there were 120 heat related deaths per year in Toronto; a steep increase from the 32 expected excess deaths during a hot summer predicted by Smoyer-Tomic and Rainham (2001). In Chicago, the 1995 heat wave caused 696 excess heat-related deaths (Whitman et al. 1997). Similarly, in France in August of 2003, 15,000 excess deaths were recorded, a rate 141% of the expected mortality rate (Canoulie-Poitrine et al. 2006).

Morbidity and mortality, however, are influenced not just by temperature. Rather, temperature, as it is influenced by humidity and wind speed, is a representation of the body's discomfort, and a better predictor of morbidity and mortality during a heat wave (Smoyer-Tomic and Rainham 2001).

Heat stress indicators are a function of temperature, humidity and/or wind speed that are related to the discomfort an individual feels during exposure. A number of indices for heat stress have been proposed. While the indicators are based on different combinations of these weather variables, no heat stress indicator has been shown to be superior for predicting heat related health outcomes (Barnett et al. 2010). For new studies, the most appropriate heat stress indicator is the one with the least amount of missing data (Barnett et al. 2010). A Dairy Cow HSI of greater than 70 units, is considered to be uncomfortable for dairy cows, and is the point at which excess mortality increases significantly (Vitali et al. 2009). Reiczigel and colleagues (2009) determined that for every heat stress day there is an immediate impact on dairy productivity, estimating that every cow produces 1.5-2 liters less milk per day during heat stress.

Heat stress mapping studies can be based on weather data obtained from remote sensing satellite imagery, but, this method is limited to the time of day that the data were obtained. Satellite images do not necessarily provide the daily maximum temperature reading in a region, and are thus a proxy for heat exposure in the region (Wilhelmi et al. 2004). Satellite imagery provides the land surface temperature (LST), while weather stations provide air temperature. Maloley (2009) found that in areas of moderate to high concentrations of vegetation, there was greater correlation in temperature readings with air temperature than LST readings. The use of weather station data in urban and rural areas will provide information for the mapping of spatial variability across a larger region. Kershaw and Millward (2012) demonstrated spatial variability in heat exposure for the Greater Toronto Area using satellite imagery for a single heat wave in an urban heat island, representing variability within the city limits. Use of automated and attended weather stations allows for hourly data collection of all relevant variables, which in turn facilitates the estimation of hourly heat stress indicators. With frequent, regular interval data collection at weather stations, rather than once daily data collection by satellite, the daily maximum heat stress indicator will be substantially more accurate.

Weather station data can be interpolated by way of optimal spatial linear prediction (i.e. kriging) (Gandin 1963). Kriging was developed on the premise that a spatial continuously varying phenomenon, such as temperature, can be interpolated between observation points by a weighted average of the observed data. The weights are based on the distance and spatial dependence between the observed data and the predicted location. The geostatistical kriging predictor is the best linear unbiased predictor (Berke 1999; Cressie 1993).

The goal of this study is to understand the heat stress index distribution for Southern Ontario. Specific objectives are: (i) map the heat stress index for southern Ontario for heat wave and control weeks, (ii) compare the spatial heat stress pattern over time, and (iii) identify areas of high-risk for heat stress related dairy cow mortality.

2. Materials and Methods

2.1 Study Area

This project has focused on Southern Ontario, which is home to about one third of the Canadian human and food animal populations. The public health unit divisions, which separate the area into Southern and Northern Ontario, were used as a boundary for the study area. The study area stretches about 600km from north to south and east to west; it boarders the St. Lawrence River, Lake Ontario, Lake Erie, and the southern portions of Lake Huron and Georgian Bay (Fig 2.1). This study area is substantially larger than most preceding heat stress study areas and different from those currently published.

2.2 Data Collection

Hourly meteorological records of maximum dry bulb temperature and dew point temperature were retrieved from weather stations located throughout the Southern Ontario region from Environment Canada (National Climate Data and Information Archive: http://climate.weather.gc.ca/; Fig. 2.1). Inclusion and exclusion criteria for weather stations were as follows: readings were recorded hourly and no more than 48 hours of data were missing over the study period, leaving 37 stations with sufficient data quality for mapping. The hourly recordings were retrieved from the National Climate Data and Information Archive (NCDIA) website hosted by Environment Canada. Exact latitude and longitude coordinates for the location of each weather station were also extracted from the NCDIA database.

The study period was defined by three heat waves and six control periods. The recognition of a heat wave required a minimum of 3 stations over the same dates. Dates were initially identified from public media sources that indicated a possible heat wave. Confirmation of heat wave dates was done manually, by confirming that 3 consecutive days reached a daily maximum temperature of 32°C or higher at a minimum of three weather station sites simultaneously. Each exposure period was then defined as the 3 day period which began the heat wave, and control periods were matched to each exposure as the 3 day frame beginning 21 days prior to the start date, and 21 days following the start date, to avoid day of the week bias. A heat wave was identified for each of the years 2010, 2011 and 2012. In 2012, a second heat wave was observed, less than 3 weeks following the one studied here. As it fell between a heat wave and its control, only the first heat wave was studied in 2012.

The heat stress indicator used in this study was developed specifically for application to dairy cows. Johnson and Vanjonack (1976) define the Dairy Cow Heat Stress Index (HSI) as follows:

$$\text{HSI} = T_{DB} + (T_{DP} * 0.36) + 41.5$$

where T_{DB} and T_{DP} denote dry bulb temperature and dew point temperature, respectively. Temperature is measured in degrees Celsius.

The heat stress index was estimated for each hour of available data, and the maximum daily value was extracted. As a result of accounting for both dry temperature and dew point temperature, the hour of highest temperature did not always correspond with the hour of most stress. Additionally, the maximum value did not occur at the same time at each station but rather was variable. The extracted daily maximum index values were then averaged to provide an overall heat stress indication for each weather station during each exposure or control period. The average for the timeframe was later used to create the heat stress map for the area.

2.3 Mapping and Analysis

The coordinates of the weather stations and boundary file for the study area were in longitude and latitude. For this study, all coordinates were projected to the Universal Transverse Mercator (UTM) Cartesian coordinate system, specifically the UTM 17N.

Isopleth maps of the spatial distribution of the heat stress index were predicted for Southern Ontario for each of the three heat waves by geostatistical kriging. Specifically, ordinary kriging based on a constant mean assumption was used in this study. Spatial dependence in the HSI data was modeled by an exponential semivariogram with and without a nugget effect to explore whether serious measurement errors occurred in the weather parameter measurements. All model parameters were estimated by weighted least squares estimation and Cressie weights (1993). The model fit was investigated using model diagnostics including the semivariogram cloud to observe for outliers and a residual semivariogram to test for unexplained spatial dependence (Berke 1999, Diggle and Ribeiro 2007).

An "average heat stress pattern" was estimated by averaging the three day average maximum HSI values over the three heat waves. As such, each location plotted, represented the average daily maximum HSI during the heat waves between 2010 and 2012.

For choropleth mapping of the total number of dairy farms per county, data regarding the distribution of dairy farms by census region was extracted from the most recent whole year (i.e. 2013) from the Dairy Farmers of Ontario database and aggregated to county boundaries by quartiles (Dairy Farmers of Ontario 2013). The dataset was used to extract relevant data for location and dairy cow census, for Southern Ontario farms. Data were aggregated to a raw total number of dairy cattle farms per health region. A map of the census divisions for the area was used to match the data to their location. This map was created using ArcGIS version 10 (ESRI 2011).

All statistical analyses were performed in R computing software version 3.0.1 (R Development Core Team, 2013), using a significance value of $\alpha = 0.05$, unless otherwise stated.

3. Results

3.1 Descriptive Results

Three heat waves were identified from 2010-2012. The exact dates for heat wave periods with respective control periods are presented in Table 2.1. HSI across Southern Ontario ranged from 65 to 84 units during a heat wave, with an Ontario average ranging between 78-79. During control periods HSI ranged between 55 to 78 units, with an Ontario average ranging between 65-75. Variability over the same period was most pronounced in 2011, during the heat wave, when the difference between maximum and minimum three-day average was greater than 18 units. Maximum daily value for heat stress was recorded at each weather station throughout the day, however the maximum HSI was observed most commonly in the early afternoon between 12:00 – 15:00 (58.2%), and rarely in early morning between 04:00 - 07:00 (0.4%). Frequency of maximum HSI per hour is presented in Figure 2.2. The most extreme heat stress value (84) was recorded in Windsor in 2011, in the southwestern tip of the study area. The highest level of heat stress recorded in 2010 was observed in Downtown Toronto (82), and in 2012, the most extreme heat stress value was recorded at the Hamilton Royal Botanical Gardens (81) (i.e., in the centre east of the study area). The lowest heat stress values during a heat wave were recorded in Erie (2012) in the south east, and Sudbury (2011) and Kilarney (2010) in the north west. During each of the 3 heat waves, extreme heat stress was widespread. In 2010 and 2011 more than 50 percent of weather stations across Southern Ontario recorded a three-day average maximum heat stress index of greater than 80.

3.2 Analytic Results

Nine heat stress maps were produced for Southern Ontario for heat wave and control periods from 2010-2012. Although each of the 9 time periods were mapped separately, there is uniformity in the spatial pattern of heat stress. During each of the 9 periods, (i.e. 3 heat waves and 6 control periods), there was spatial autocorrelation to 80 kilometers, regardless of the period type (Table 2.2). This is known as a proportional effect. The proportional effect suggests that the spatial structures are the same; however there is variability in the levels of heat stress (Berke and Waller 2010). In the case of a proportional effect, the practical range is the same regardless of period but there are changes in the sill value. While the level of stress varied, the pattern for heat waves and control periods was visually similar over time (See Fig 2.3: A-C, E-J). In the southeastern area of the study region, including Toronto and Hamilton, heat stress was always higher than surrounding areas (Figure 2.4). Therefore, the greater metropolitan area of Toronto is expected to experience the most intense heat stress during a typical heat wave. In the northwestern portion of the study area the heat stress is generally lower than in surrounding areas. In 2010 and 2011 the Ottawa region in the north also experienced heat stress values above 80 units. The 2012 heat wave occurred in June, and may be the reason for the variability in pattern. During three of the periods evaluated, there was a strong relationship between the stress values and the north-south coordinate. At weather stations located farther north, fewer high levels of heat stress were observed. Furthermore, a trend from east to west, (i.e. in the prevailing wind direction), was also observed. The east to west trend represents what appear as pockets of extreme heat stress in some areas.

As similar spatial heat wave patterns were observed, an average heat stress map was created as well. The map indicates the average maximum of the three heat waves, and illustrates how “average heat stress distribution” presents in Southern Ontario (See Fig 2.3D). The map indicates that during an average heat wave, heat stress crosses the critical daily heat stress value threshold for the length of the 3 day heat wave period (Vitali et al. 2009). Moreover, during an average heat wave, the area from Lake Erie to Lake Ontario, and westward to Lake Huron, where the majority of dairy farming in Southern Ontario occurs, reaches an average maximum HSI of 80 or higher daily.

A choropleth map of the dairy farm density indicates a concentration of the industry in the mid-western region of Southern Ontario and along the St. Lawrence River approaching Ottawa (See Fig 2.5). The highest heat stress region for dairy farming in Southern Ontario occurs in a band stretching from Lake Ontario to Lake Huron in the Great Lakes Basin. Additionally, a large number of dairy farms are located along the St. Lawrence River, northeast of the major metropolitan areas of Southern Ontario. Limited dairy farming occurs along Lake Erie in the most southern portion of Ontario or in the northwestern portions of Southern Ontario.

4. Discussion

This study illustrates that heat waves are a current problem in both urban and rural areas of Southern Ontario; it will be crucial to develop heat abatement strategies for rural communities and their farming industry. Weather station data provide an accurate source of ambient air temperature outside of dairy barns; however the air temperature within a barn is often much higher (Schüller et al. 2013). This is particularly true for food animals such as dairy cows which are producing heat as a result of their high metabolic rate. As a result, it is likely that heat stress which dairy cows experience within the barn is underestimated by these maps. Schüller et al. (2013) estimate that weather stations underestimate ambient temperature by 6.4°C, and HSI within the barn by 11.1 HSI units. These results only increase the likelihood that dairy cow morbidity and mortality are increased during a heat wave in Southern Ontario. Based on the average heat stress determined in this study (77-79), and Schüller et al.'s adjustment of 11 HSI unit increase inside the barn, the average predicted in-barn-HSI during a heat wave is 88 or higher. With that, increased dairy cow morbidity and mortality on farm is likely during a heat wave in Southern Ontario depending on the efficacy of heat abatement strategies in the barns.

Moreover, the use of air temperature rather than satellite imagery accounts for problems addressed by Maloley (2009) and Kershaw and Millward (2012), because there is increased association between air temperature and rural or suburban temperature than urban temperature and physiological response. In Canada, where large areas generally include both urban and rural space, air temperature will better represent the area as a whole than satellite imagery alone. Because the spatial pattern of heat stress during recent heat waves in Southern Ontario is stable in time it is considered useful to average the maps to create an HSI spatial pattern predictive of future heat waves. This average distribution of heat stress during a heat wave can predict likely areas of increased stress, and can estimate the amount of stress in a given area, prior to a heat wave occurring.

While addressing issues of LST to air temperature correlation, new limitations did arise. This study was limited by the number of weather stations across the region which provided sufficient quality of data for inclusion. Hourly weather data were available from only 37 of 92 weather stations that collected daily records throughout the 2010-2012 periods. As the distance between stations increases or the density of stations decreases, the kriging prediction errors presumably increase. This study covers a larger land area than most previously completed studies of its kind and focuses on an area with different land use than previously completed work in Canada.

While there is visual similarity between all 3 heat waves, there is more similarity between the heat stress maps for 2010 and 2011. The 2012 heat stress map may be different for 2 reasons. Firstly, only one of the two heat waves which occurred in 2012 was mapped as the first fell between the heat wave and a control week. Secondly, the heat wave mapped for 2012 occurred in June, and is earlier in the summer than both of the 2010 and 2011 heat waves. These differences may account for the dissimilarities in the 2012 map compared to the other two years. This trend is a possible problem for future as heat waves are increasing in frequency and occurring earlier as a result of climate change.

As heat waves increase in frequency and intensity, as commonly predicted by climate change models (Meehl and Tebaldi 2004; Wilhelmi et al. 2004), risk maps for heat stress will become a prominent tool in human and animal health research associated with climate change. The maps from this study indicate that the southwestern portion of the study area is both high risk and highly populated with dairy cows. This pattern is predictable across the 3 heat waves investigated in this study, and shows similarities to maps created for control periods, indicating that Southern Ontario may be less suitable for dairy farming in the future.

As it is not reasonable to suggest farmers relocate herds, it is recommended to frequently monitor heat and heat stress in dairy barns throughout the summer months (June-August). Farmers who are aware of increased stress within the herd may be able to utilize heat abatement strategies to reduce the discomfort of individual cows or the risk of heat-related fatality in the herd. Current heat abatement strategies have been reviewed by Collier et al. (2006), and include changes to both housing and milking facilities, such as air movement (fans), soaking the cow's body, evaporation of cool air and facilities which decrease solar heat transfer. Evaluation of the effectiveness and sustainability of these strategies under heat wave conditions in Ontario is currently lacking.

The study of control periods in addition to heat waves indicates a substantial increase in heat stress during a heat wave. This increase indicates that a serious increase in dairy cow morbidity and mortality is to be expected. To validate the performance of heat stress maps to predict the effect of heat stress on cows, heat stress risk maps might be compared to dairy cow mortality maps or maps of increased or decreased production.

5. Conclusion

A methodology for heat stress mapping was proposed. Heat stress was mapped over extended (3-day) periods and larger geographical areas using hourly air temperature and humidity readings rather than satellite imagery. Heat stress during heat waves from 2010-2012 was mapped to demonstrate the predictability of heat stress risk in Southern Ontario, and compared with the most commonly used areas for dairy cattle farming. A follow-up study is recommended to validate the increased risk of mortality or production losses in dairy cows in

Southern Ontario during heat waves. It is also recommended that farmers monitor their herds more frequently during heat waves and apply heat abatement strategies such as fans and soaking to mitigate heat stress. The development of these maps should assist in developing policies to improve the welfare and health of dairy cows during extreme heat stress. With an expected increase in the frequency and intensity of heat waves in the coming decades, such a mapping framework and methodology are essential for the development of effective, targeted heat abatement strategies.

6. Acknowledgements

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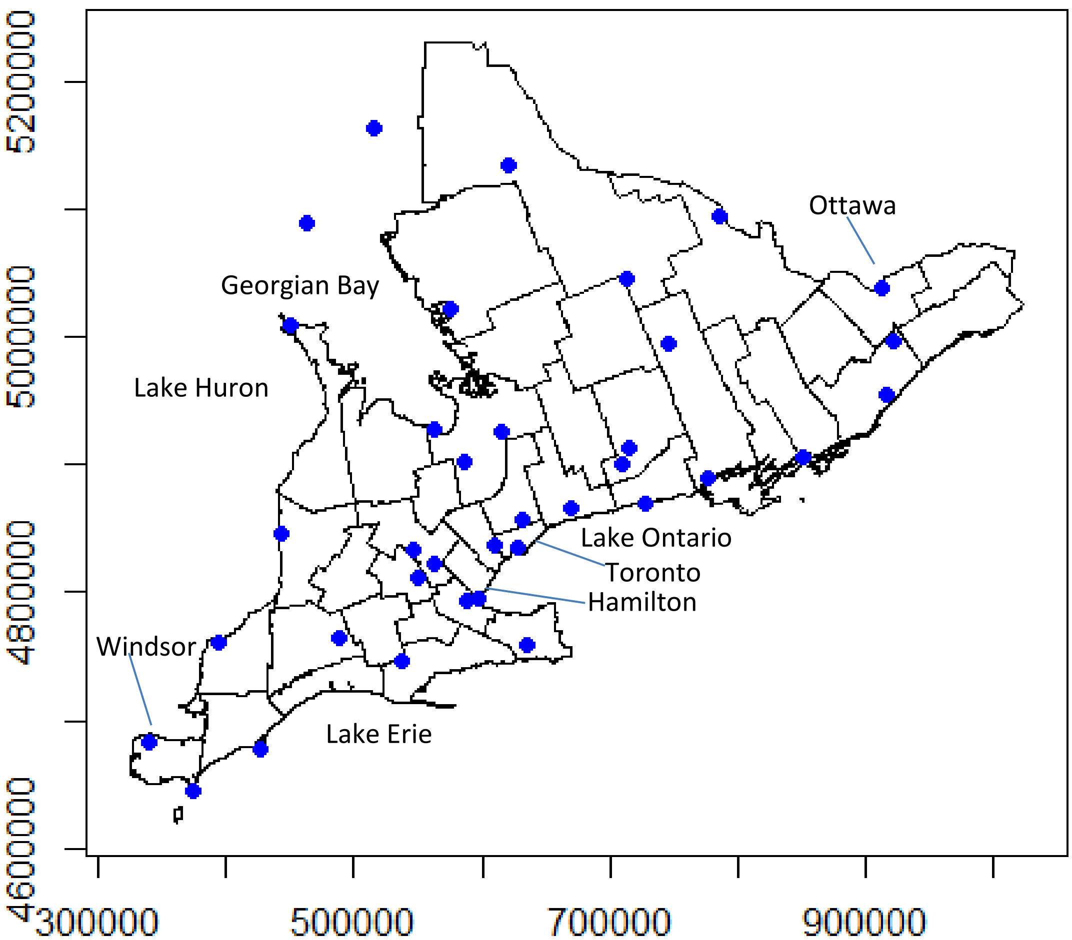


Fig. 2.1- Location of meteorological stations. Locations of 37 meteorological stations in and around Southern Ontario which provide hourly interval data collection. Map units are in meters.

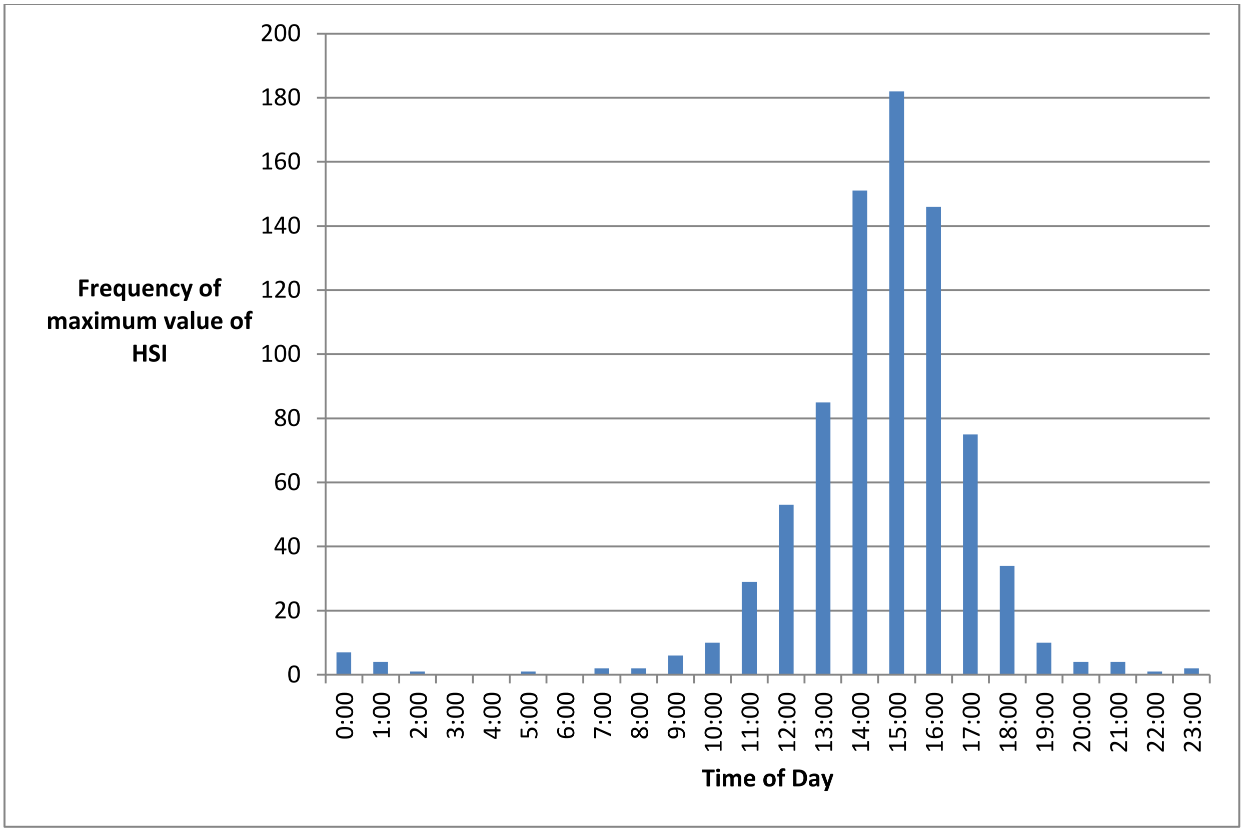
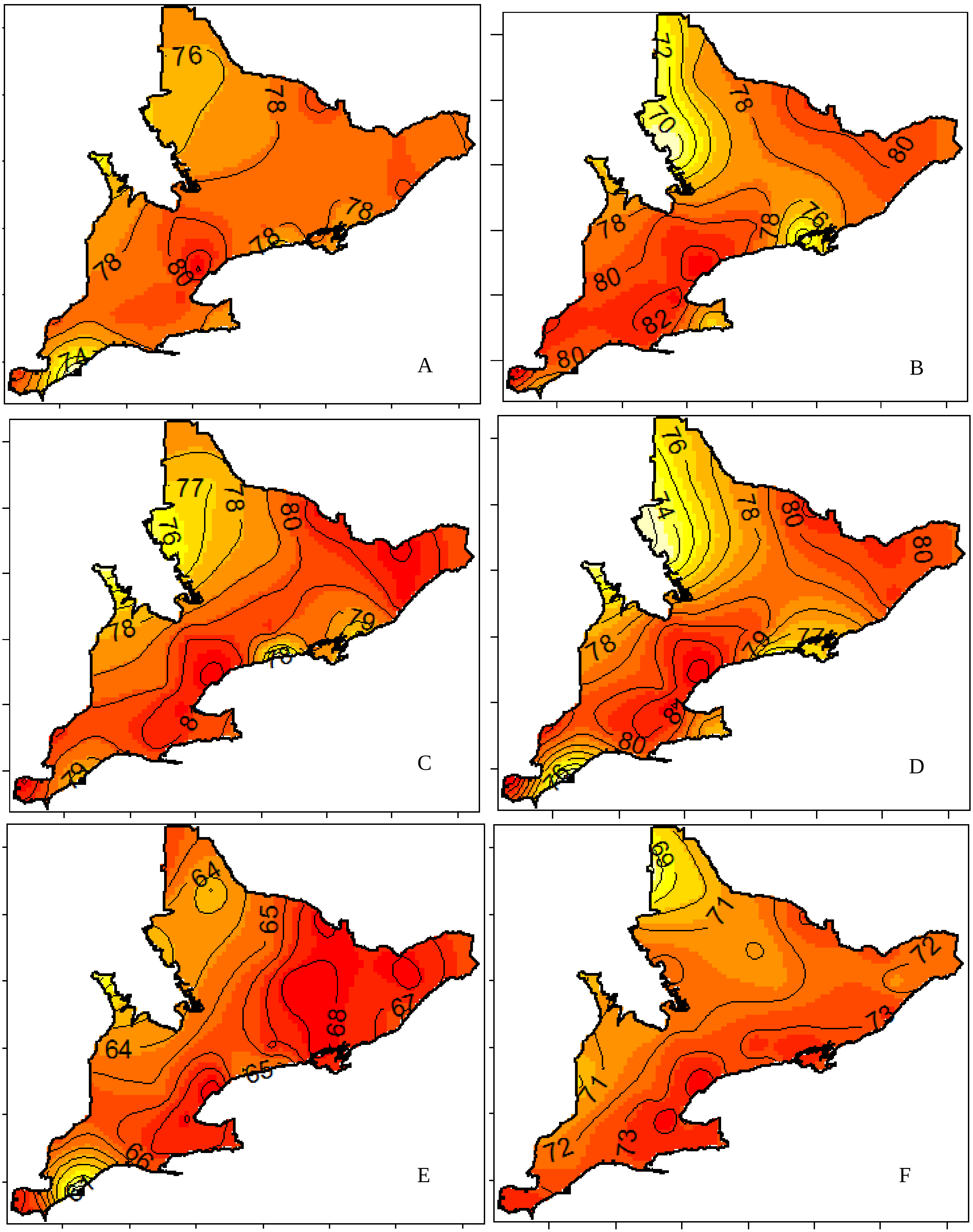


Fig. 2- Time of day for most extreme HSI. Frequency of most extreme HSI relative to hourly intervals



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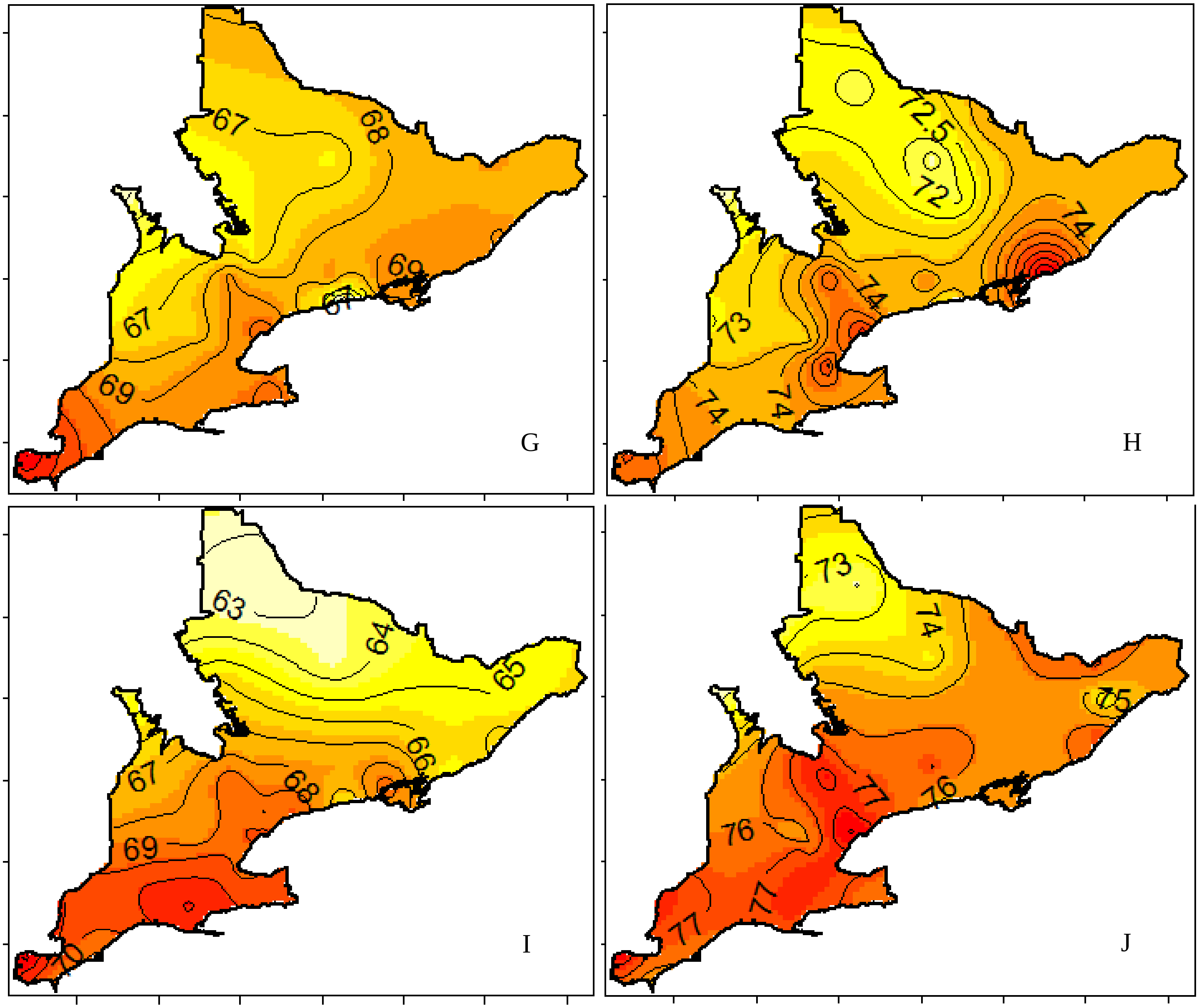

Fig 2.3- Maps of the predicted heat stress index distribution for heat waves from 2012 (A), 2011 (B), and 2010 (C). Heat stress map of Southern Ontario for an average heat wave based on heat waves from 2010, 2011 and 2012 in a combinatory measure (D). Maps of the distribution of heat stress during each of the 6 control periods: 2012 pre heat wave (E), 2012 post heat wave (F), 2011 pre heat wave (G), 2011 post heat wave (H), 2010 pre heat wave (I), 2010 post heat wave (J).

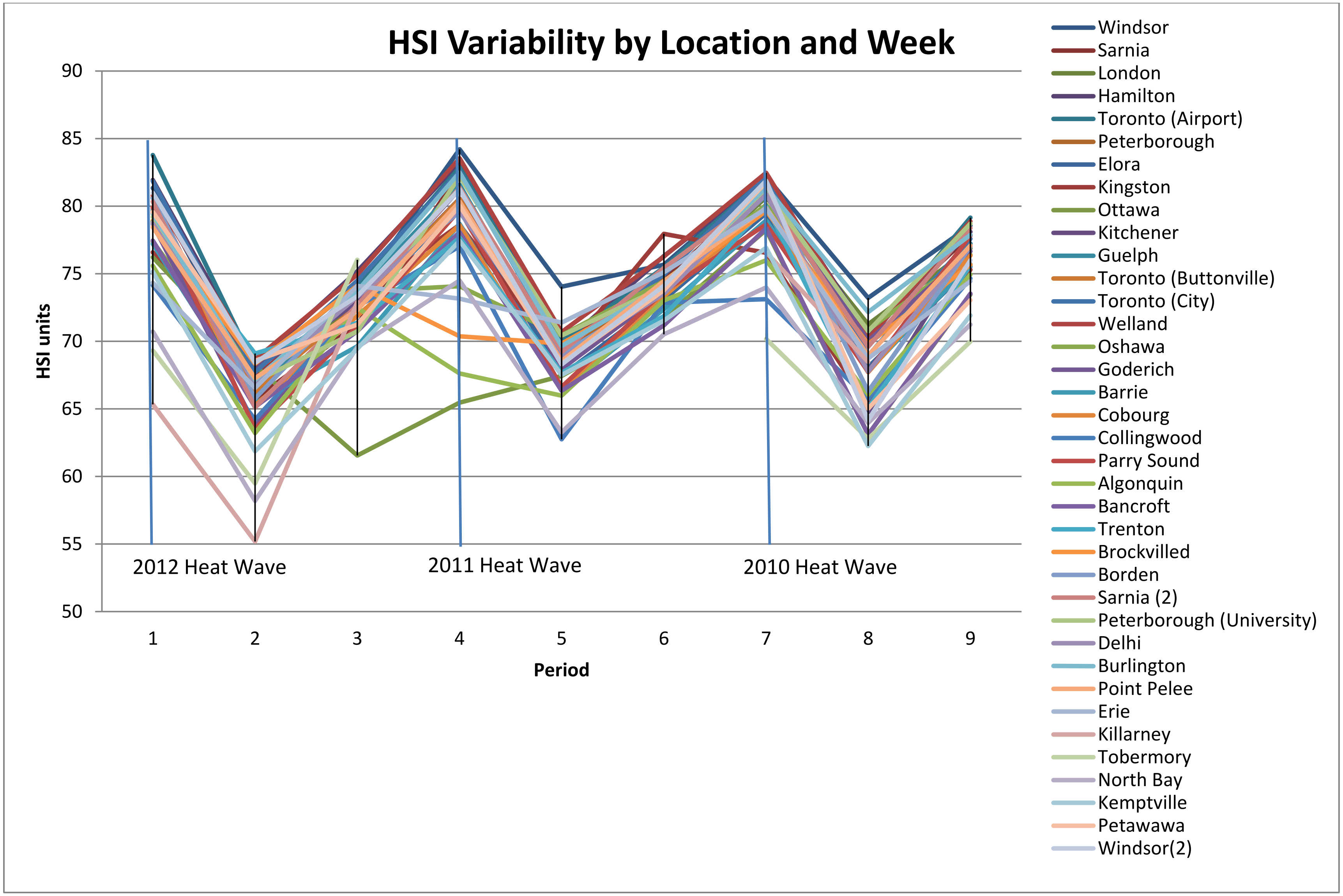

Fig 2.**4-** Depiction of heat waves and controls by location over 3 heat waves and 6 control periods.

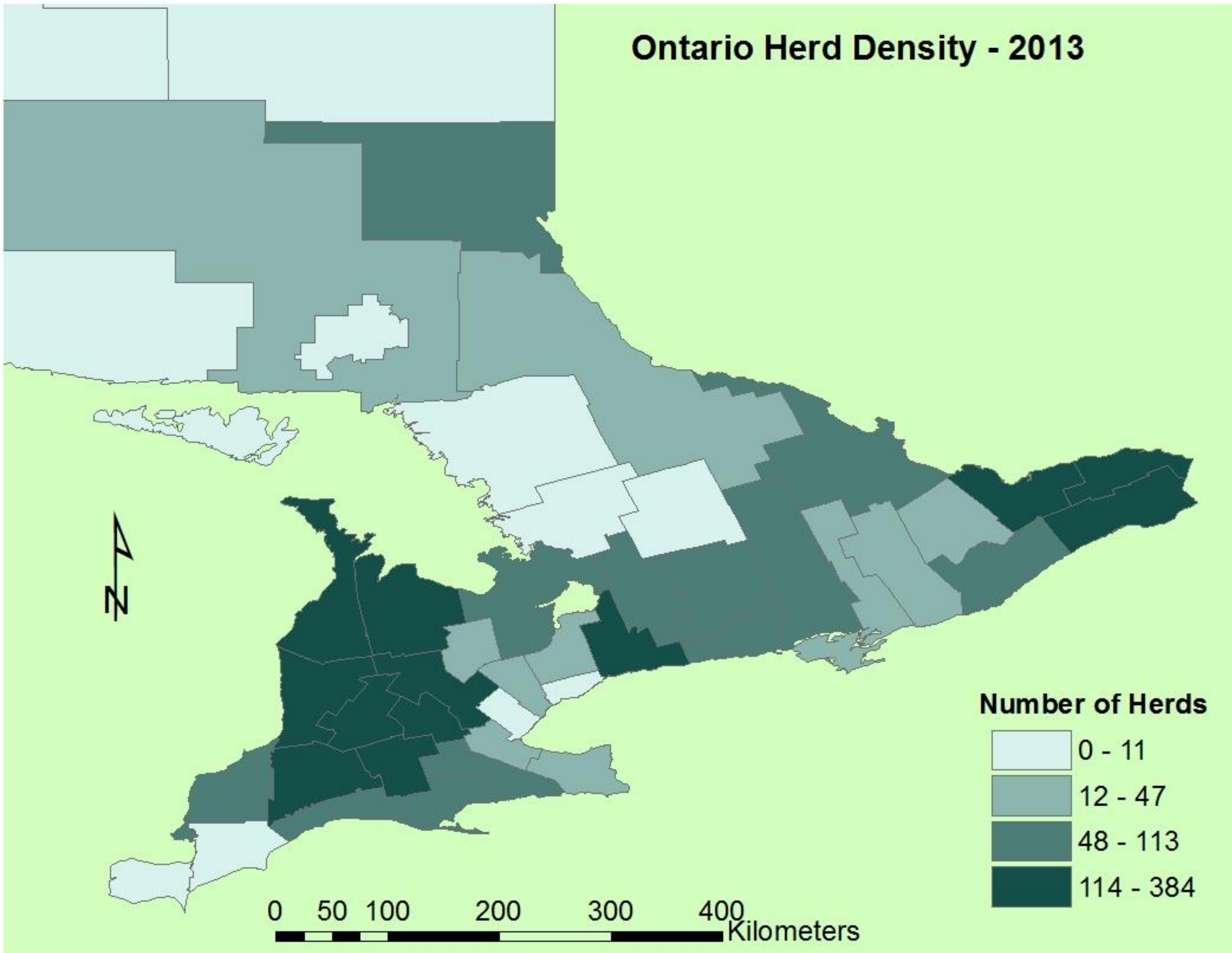

Fig. 2.5- Dairy cow farm density map. Total number of dairy farms per region, aggregated by county in Southern Ontario.

Table 2.1- Dates of selected heat wave and control periods for Ontario from 2010-2012.

Year	Heat Wave Period	Control Period 1 (Preceding)	Control Period 2 (Following)
2012	June 19- 21	May 29- 31	July 10-12
2011	July 20-22	June 29- July 1	Aug 17-19
2010	July 5-7	June 14-16	July 26-28

Table 2.2- Semivariogram model parameters for heat waves and control periods in Southern Ontario from 2010-2012

Period	Year	Type	Sill (Sigma^2)	Range (Phi) (km)
1	2012	Heat wave	6.9	80
2	2012	Control	5.9	80
3	2012	Control	2.3	80
4	2011	Heat wave	14.5	80
5	2011	Control	2.8	80
6	2011	Control	2.2	80
7	2010	Heat wave	5.9	80
8	2010	Control	5.6	80
9	2010	Control	1.8	80

CHAPTER 3:

Heat Stress Related Dairy Cow Mortality During Heat Waves and Control Periods in Rural Southern Ontario from 2010-2012

***As prepared for submission to BMC Veterinary Research**

Abstract

Heat stress is a physiological response to extreme environmental heat such as heat waves. Heat stress can result in mortality in dairy cows when extreme heat is both rapidly changing and has a long duration. As a result of climate change, heat waves, which are defined as 3 days of temperatures of 32°C or above, are an increasingly frequent extreme weather phenomenon in Southern Ontario. Heat waves are increasing the risk for on-farm dairy cow mortality in Southern Ontario. Heat stress indices (HSIs) are generally based on temperature and humidity and provide a relative measure of discomfort which can be used to predict increased risk of on-farm dairy cow mortality. In what follows, the heat stress distribution is predictable over space and can be presented by maps. Similarly, on-farm mortality is predictable and can be mapped.

Mortality records and farm locations for all farms registered in the CanWest Dairy Herd Improvement Program in Southern Ontario were retrieved for 3 heat waves and 6 three day control periods from 2010-2012. A random sample of controls (2:1) was taken from the data set to create a risk-based hybrid design. On-farm heat stress was estimated using data from 37 weather stations and subsequently interpolated across Southern Ontario by geostatistical kriging. A Poisson regression model was applied to assess the on-farm mortality in relation to varying levels of the HSI.

For every one unit increase in HSI the on-farm mortality rate across Southern Ontario increases by 1.03 times ($CI_{95\%}$ (IRR)= (1.025,1.035); p= $\leq$ 0.001). With a typical 8.6 unit increase in HSI from a control period to a heat wave, mortality rates are predicted to increase by 1.27 times.

These findings will aid policymakers (e.g., local government) and farmers in making informed decisions about best practices for cooling and heat abatement strategies to improve farm animal welfare.

Keywords

Southern Ontario, Heat Stress, Rural, Dairy Cow, Mortality

1. Introduction

Heat stress is defined as a physiological response to environmental heat which can cause such signs or symptoms as discomfort, increased respiration rate, dehydration, changes in cardiac function, and in severe cases may result in death (Josseran et al. 2009). Heat stress occurs not only in humans, but in livestock species as well. Documented heat stress related mortality has occurred in sows (D'Allaire et al. 2009), chickens (Quinteiro-Filho et al. 2012) and in dairy cattle (Vitali et al. 2009).

Dairy cows are highly susceptible to changes in temperature, particularly to rapid increases in temperature or long periods of extreme heat. Recent increases in production, which result in higher metabolic rates, have exacerbated this vulnerability to extreme heat in dairy cows (Collier et al. 2006). This susceptibility can result in losses in productivity of 1.5 to 2 L of milk per cow per day (Reiczigel et al. 2009), and increased morbidity and increased mortality (Vitali et al. 2009). For the average dairy cow farmer in Southern Ontario, a 3-day heat wave would result in losses of $253 - $337 based on average milk prices of $0.75 /L and farm sizes of 75 cows in milking. For a farm where one cow dies as a result of the heat wave (excess death) the economic impact is between $2,000 - $2,500 dollars. In the United States, the economic impacts related to heat stress in dairy cows have been estimated to be approximately $897 million in losses per year (St-Pierre et al. 2003).

Heat related dairy cow mortality is not only a problem of the future. Rather, mortality caused by heat waves is a growing concern, dating back decades. Prior research in California demonstrated that during periods of high temperature in the summer, on-farm calf mortality increased substantially (Martin et al. 1975). In Italy, a threshold for increased dairy cow mortality was established based on a combinatory estimator of heat and humidity related discomfort known as the heat stress index (HSI). Vitali et al. (2009) determined that increased dairy cow mortality was expected in Southern Italy when the HSI increased above 70 units. In Hungary, models of future heat stress days predict increases of up to 27 heat stress days per year in areas with substantial cattle farming by the year 2040. This rise in heat stress days is expected to increase the on-farm mortality dramatically (Solymosi et al. 2010). A study in the United States proposed that the impacts of heat waves on mortality are increasing as per cow production increases resulting in increases in the cow's metabolic rate and metabolic heat production (Collier et al. 2006).

A heat wave is defined by Environment Canada as 3 consecutive days of temperatures of at least 32°C daily maximum temperature (Environment Canada 2013); however, a variety of other definitions exist for a heat wave. A heat wave by this definition combined with any level of humidity is sufficient to cause an HSI of at least 70 units based on the Dairy Cow Heat Stress Indicator developed by Johnson and Vanjonack (1976). The Dairy Cow HSI estimates heat stress using parameters known as the dry bulb temperature and the relative humidity readings (Johnson and Vanjonack 1976). As a result, a heat wave is commonly associated with heat stress in individuals, although not all cows will experience heat stress characteristics beyond the 70 unit threshold. Instead, heat stress is more common in individuals when the HSI is above the threshold, and can be more pronounced leading to increased risk of mortality on-farm (Vitali et al. 2009).

The data for this study came from databases maintained by Dairy Farmers of Ontario (DFO 2014) and CanWest Dairy Herd Improvement (DHI). All farms in Southern Ontario are licensed to produce and sell milk by the DFO, but participation in milk recording with DHI is voluntary. In Canada, CanWest DHI (DHI 2013) offers value added services to dairy farmers such as pregnancy testing, disease testing and computerized record keeping. This pay for service registered program involved 2,898 of 4,084 (71%) dairy farms in Ontario in 2009 (Hand et al. 2012). Records kept by DHI greatly exceed industry requirements and provide a thorough description of what is occurring at the farm level.

The predictions regarding the future impacts of heat waves consistently point to increases in frequency, intensity and duration (Meehl and Tebaldi 2004; Wilhelmi 2004; McMichael et al. 2006; Haines et al. 2006). With increased severity of heat waves there is expected to be an increased impact of heat waves on health and increases in the economic impact these heat waves have in Southern Ontario and specifically on the dairy industry.

Poisson regression modeling can be used to estimate the incidence rate ratio (IRR) or mortality rate from counts of death records such as those collected by the DHI. Statistical modelling of spatially correlated data such as heat stress (Chapter 2) can be used to better understand these count data.

The goal of this study was to understand the current impact that heat waves have on mortality rates of dairy cows on farms in Southern Ontario. Specifically, the objectives of this study were: (i) to collect and summarize mortality data for dairy farms in Southern Ontario during heat waves and control periods; (ii) to estimate the increase in mortality rate of dairy cows on-farm in Southern Ontario as the HSI increases; and (iii) to determine how risk for on-farm dairy cow mortality varies across Southern Ontario during heat waves.

2. Materials and Methods

2.1 Data Collection

Heat waves were identified using a search of the popular press which indicated possible heat wave dates. As a result of the variability in definitions for a heat wave, each heat wave was confirmed to meet the Environment Canada definition of a heat wave. Control periods were selected based on dates of confirmed heat waves to start 3 weeks (21 days) prior to the start of the heat wave and 3 weeks following the start of the heat wave. Control periods were matched for day of the week to control potential biases for daily activities.

Heat stress maps were created as part of a previous study to map the distribution of heat stress across Southern Ontario (Chapter 2). Briefly, weather data were obtained from the National Climate Data and Information Archive (Environment Canada 2013) for 37 hourly weather stations across Southern Ontario on 27 dates (i.e., 3 heat waves and six 3-day control periods) and the hourly HSI was estimated for each point location.

The HSI was estimated using the Dairy Cow HSI developed by Johnson and Vanjonack (1976):

$$\text{HSI} = T_{DB} + (T_{DP} * 0.36) + 41.5$$

where T_{DB} and T_{DP} denote dry bulb temperature and dew point temperature in degrees Celsius, respectively. In a study comparing 5 heat stress indicators across 105 cities, including the HSI, Bartnett et al. (2010) concluded that all indices are equally predictive. They thus proposed to choose an index based on data availability. Therefore, in this study, the HSI as defined above, was chosen over the commonly used Temperature Humidity Index (THI). Geostatistical kriging was used to predict the spatial pattern of heat stress for the entire study area.

The average daily maximum heat stress for each point location was estimated by averaging the true daily maximum HSI from each day over the 3-day period. Ordinary kriging with exponential semivariogram structures was used to predict the HSI during 3 heat waves and 6 control periods (3 days each) across Southern Ontario.

Individual dairy cow and farm data were collected from the CanWest DHI and the DFO databases in 2013. Data collected from the CanWest DHI database included mortality records, status upon leaving the farm, herd size, breed and birth date (age). Exact global positioning system (GPS) location data for each farm was collected from the DFO database, along with a herd identification number. Farms were matched by the DFO identification number which is captured by the DHI database. Farm coordinates measured by GPS and mortality records were used to create a point map of on-farm deaths for each of the 3 years.

A map of dairy cow farm density was created using DHI and DFO location data in ArcGIS version 10 (ESRI 2011), aggregated at the county level.

Farm locations were used in conjunction with heat stress maps to predict the level of heat stress at each farm location captured from the DHI database.

2.2 Modelling and Analysis

All farms with a death event during a heat wave (case farms) were included in the study. Two random control farms were selected for each case farm, during the same heat wave period. Control farms were selected from the pool of dairy farms not reporting a death during the heat wave, which were registered with CanWest DHI during both control periods. Farms were selected using a random number generator and were chosen with replacement for each year (i.e. farms could be selected only once per year but selected again as a control for other years). The dataset of 2 controls to each mortality record were used to create a risk-based hybrid design where the case farms and control farms were compared during the prospective and retrospective control periods. The term risk-based hybrid design is intended to imply that all cases from an exposure were selected for inclusion, as well as 2 control farms for each. This hybrid study design borrows from case-control design along the centre vertical line of the sampling depiction (Figure 3.1) and from a case-crossover design in the horizontal lines of the depiction. A case-control study design would not have allowed for the estimation of mortality rates; however, the use of case farms and control farms created a cohort from which excess mortality rates during a heat wave as compared to the two control periods can be estimated. In this study, the excess mortality during heat waves was of interest. Refer to Figure 3.1 for a detailed illustration of the sampling for this study.

Quasi-likelihood estimation was used in a Poisson modelling framework rather than maximum likelihood estimation because of its ability to handle over-dispersion. A Poisson model assumes that the mean and variance are equal, while a quasi-likelihood estimation of the model has the capacity to work with data which do not have equal means and variances. Over-dispersion is common in clustered data and also frequently occurs in spatial data sets.

Poisson regression models were fit by quasi-likelihood estimation to test the univariable significance of a variety of predictors on the change in mortality rate of dairy cows on-farm during a heat wave compared to a control period. These predictors included: locations expressed as easting and as northing, HSI, and an indicator for the presence of a heat wave. Variables that appeared significant at a relaxed significance level of α=0.2, were entered into a multivariable Poisson regression model. The Quasi-likelihood model was used to estimate dispersion of the model. The Poisson regression model was fit using backward stepwise modeling procedures until all remaining variables in the model were significant (α=0.05). A random effect was used for farm. Fit of the model was assessed using a quantile-quantile plot of residuals.

All analyses were done in R Statistical Package (3.1.0), using a significance value of α = 0.05, unless otherwise stated.

To test for geographical areas of high risk, a spatial scan test (Kullldorff, 1997) was applied across Southern Ontario to determine if certain areas were at increased risk of heat stress related mortality. The mortality ratio was estimated by the spatial scan test based on the number of mortality records per farm and the number of cows on that farm. Spatial coordinates in latitude and longitude were translated to Cartesian coordinates in Universal Transverse Mercator (UTM) 17 North, for analysis. A purely spatial scan test (i.e. no temporal analysis) using the Poisson distribution was used to test for clusters of high or low incidence of on-farm mortality. Analysis was done using 999 Monte Carlo permutations and a maximum scanning window of 50% of the population. Analysis was conducted in SaTScan version 9.3 (Kulldorff et al. 2014) using a significance value of $\alpha = 0.05$.

3. Results

3.1 Descriptive results

A total of 281 death records for three heat waves from 2010-2012 were retrieved from the DHI database (Table 3.1). In total, 47 deaths were recorded on 2,953 farms on the 9 dates in 2012, 126 deaths on 2,894 farms in 2011 and 108 deaths on 2,842 farms in 2010. During a heat wave the average total number of on-farm dairy cow deaths registered with DHI across Southern Ontario was 94 deaths per 3-day period (Table 3.2). This is approximately 1 death per 30 farms. Deaths during all heat waves followed a similar spatial pattern to the density of dairy farms (Figure 3.2) and the distribution of heat stress in Southern Ontario during a heat wave (Chapter 2). As a result, on-farm dairy cow deaths most frequently occurred in the southwestern portion of Ontario or the central and northeastern areas (Figure 3.3). Most cows were 3 years old at the time of death (i.e. mode) and the mean age of cows at the time of on-farm death was 5 years. Cows ranged in age from 1 year to 15 years at the time of death. Holstein-Friesian represented 94% of on-farm dairy cow deaths, and similarly, 94% of the dairy cow population in Southern Ontario is Holstein-Friesian (DFO 2013). Of all farms included in the study, 229 farms reported only 1 death over the 27 days of the entire study period. The maximum number of deaths on a single farm during a heat wave was 4 (Figure 3.4). Farms included in this investigation ranged in size from 22 cows to 1,268 cows, while deaths were most frequently reported on-farms with 51-100 cows (38%; Figure 3.5).

As reported previously (Chapter 2), heat stress in Southern Ontario follows a predictable pattern during heat waves. Heat stress is highest around major metropolitan areas such as Toronto and is also concentrated in the areas of southwestern Ontario near London and in the northeast around Ottawa. Maps illustrating heat stress distribution during each of the 9 periods and locations of on-farm dairy cow deaths in Southern Ontario are displayed in Figure 3.3.

3.2 Analytic Results

In univariable Poisson regression analysis the variables HSI and Cartesian coordinates (i.e. northing and easting) were significant predictors of increased on-farm dairy cow mortality. Spatial coordinates suggest a trend in the mortality where easting from the most eastern point to the most western point of the study region predicts an increase in mortality rate of 8% (1.08 times; $p = 0.01$; Table 3.3A). When considering only the HSI in univariable quasi-likelihood Poisson regression, a one unit increase predicts a 3% (1.03 times; $p \leq 0.001$) increase in on-farm mortality rate. Backwards elimination using the full model with all significant univariable predictor variables (HSI, easting and northing) left the predictor HSI as the only significant variable ($p \leq 0.001$), see Table 3.3B. A spatial Poisson regression model was attempted, but it did not fit the data well and was rejected.

In the final model, a one unit increase in HSI results in a 3% increase in the on-farm mortality rate ($CI_{95\%}$ (IRR)= (1.025,1.035); $p \leq 0.001$), see Table 3.3C. The average HSI on-farm during a control period was 71.1 units and during a heat wave 79.7 units. This average 8.6 units difference in HSI between a control period and a heat wave suggests an increased on-farm dairy cow mortality rate of 27% during heat waves.

No significant circular clusters (p=0.439) were located in Southern Ontario for on-farm dairy cow mortality during heat waves.

4. Discussion

Dairy cow mortality is associated with heat wave related heat stress and follows a predictable pattern. While a single unit increase in HSI may have limited impacts on the number of farms affected by on-farm mortality, a substantial increase such as the average 8.6 unit increase in HSI accompanying a heat wave has dramatic impacts on farmers. From a population-level perspective, a 27% increase in mortality during a heat wave will on average result in an additional 26 deaths in southern Ontario per heat wave. Since most deaths were one per farm, this suggests that approximately 26 additional farms will be affected. That is approximately 1% of all farms affected by an excess death per heat wave. In contrast, all farms in Southern Ontario will be affected by milk production losses during a heat wave. This increased impact is part of the loss of productivity associated with heat waves as it does not include such negative effects as decreased milk productivity, reduced fertility and additional morbidity.

Similarly, while the HSI is a better predictor for on-farm dairy cow mortality than Cartesian coordinates, farms located further west are at increased risk of mortality. Both heat wave status and Cartesian coordinates are represented by the spatially correlated HSI variable which was predicted to farm locations using geostatistical kriging of weather station data. The heat wave indicator is a binary variable and thus carries less information than the HSI index which is a continuous variable that more precisely measures heat related discomfort. Cartesian coordinates only allow modelling of a linear trend surface related to spatial variation of mortality. On the other hand, the HSI is spatially varying, but its geographic pattern is more complex than an artificial linear trend surface. Therefore, HSI is a better descriptor for mortality than the heat wave binary variable or the spatial coordinates. For the same reason, a spatially correlated Poisson regression model was not adequate for modeling on-farm dairy cow mortality: as the HSI accounts for spatial variation in the model, additional spatially correlated random effects would result in an over-parameterized model. Indeed the range of the spatial Poisson regression model was negligible, i.e. shorter estimated than minimum inter-farm distances.

No significant circular clusters were found for increased or decreased mortality in Southern Ontario for on-farm dairy cow mortality. The reason no significant clusters were found may have to do with the circular restrictions of the scan test applied in SaTScan (2014). The application of an irregularly shaped scan test such as the elliptic scan test is an alternative method; however there is no justification for testing an irregularly shaped cluster window of weather phenomena. A single scan test was applied to the data because of the similarity of spatial heat stress patterns in Southern Ontario over time (Chapter 2). A large number of deaths occur in the southwest and northeast of Southern Ontario, areas where there are many dairy cow farms. An explanation may be that the entire study area seems to be affected by the necessarily broad scale weather systems which generate a heat wave. Therefore, small or localized clusters related to dramatic increases or reductions in temperature over 3 days are unlikely and thus, so are changes in the pattern of the outcome, mortality. While no clusters of mortality exist, this does not diminish the relevance of a temporal relationship in which mortality of on-farm dairy cows increases with increasing HSI during a heat wave.

Holstein-Friesian cows are known to be the most susceptible dairy cow breed to heat stress (Jan and Nichelmann 1993); however, no more deaths were observed in Holstein-Friesians than other dairy cow breeds in this study. In Ontario, other breeds are relatively rare and there may be insufficient power to test this.

This study provides evidence for the current impact of heat stress on dairy cow mortality in Southern Ontario. The reality of statistically significant increases in mortality as the HSI increases illustrates the potential need for more effective heat abatement strategies. This study most likely underestimates the severity of this problem as heat waves have been shown to cause further production losses on farm necessitating heat abatement strategies (Collier et al. 2006). While it can be suspected that a variety of heat abatement strategies are applied in Ontario, their use pattern and effectiveness has not been systematically investigated. Heat abatement strategies have been shown to decrease productivity losses on-farm by 25% when used intensively rather than minimally (St. Pierre et al. 2003). Other effective strategies in addition to traditional heat abatement strategies include management style, nutritional changes and improved breeding techniques (Gauly et al. 2003). If, in fact, heat abatement strategies are being employed and are reducing the number of deaths, than the impact of heat waves or heat stress on mortality may be underestimated. There is evidence that the HSI inside the barn is as much as 11 units higher than outside the barn (Schűller et al. 2011). This underestimation of the HSI should be constant across Southern Ontario, thus these estimates of the relationship between HSI and mortality from the Poisson regression modelling should not be affected. If regional impacts exist, they are likely the result of farm management practices or barn style rather than the direct result of in-barn to exterior HSI differences. Future work exploring farm management practices, barn style and environmental factors should be considered. It would also be interesting to investigate heat abatement strategies with respect to effectiveness, efficiency and sustainability.

This study makes a very conservative estimate of the of on-farm mortality rates associated with heat waves in Southern Ontario. Research is suggestive that heat waves will increase in frequency, intensity, duration and size (Meehl and Tebaldi 2004), all of which can increase the on-farm mortality rate beyond what is currently reported. This data set, i.e. the CanWest DHI, provides data on only 70% of farms in Ontario (Hand et al. 2012), and thus probably estimates 70% of the true on-farm mortality rate. The data does not include calves and heifers, which have also been reported to have increased mortality rates during extreme heat (Martin et al. 1975). This is a welfare issue which merits further investigation and attention for dairy cows and other livestock species in Southern Ontario.

In light of the relative increase in mortality associated with current heat stress levels, predictions of future increases in heat waves and heat stress days highlight the importance of this issue for decades to come. Since 2003, there have been 1 or more heat waves per year in Southern Ontario, each threaten farm animal production and welfare in the province. This trend is predicted to increase substantially over the next number of years (Meehl and Tebaldi 2004; Wilhelmi 2004; McMichael et al. 2006; Haines et al. 2006). As heat stress increases, on-farm mortality rates are illustrative of a “tip of the iceberg” for other economic losses.

Heat wave warnings issued through a variety of media channels have been proven to decrease the risk of heat-related mortality (Metzger et al. 2010). It is reasonable to expect that the same would be true if these warnings would be coupled with a warning for farm animals.

5. Conclusion

Heat wave induced heat stress is an existing problem which poses underestimated threats to the dairy industry in Southern Ontario. On-farm mortality rate increases by 8% (1.08 times) for easting across the region (approximately 400 km). A one unit increase in HSI is predicted to increase the mortality rate by 3% (1.03 times) and the typical rise associated with a heat wave increases the mortality rate by 27% compared to a control period. While climate change models unanimously predict an increase in the frequency and severity of extreme weather events such as heat waves, this problem will continue to grow in Southern Ontario. In consequence the excess mortality rate due to heat stress increases, so too do the combined economic losses associated with heat stress in farm animals. While farmers may employ heat abatement strategies, the effectiveness of these measures is unknown in Canada. Moreover, if these measures are in place during a heat wave, the excess mortality due to heat stress in Southern Ontario may be underestimated and differential use of these measures could impact the apparent spatial patterns.

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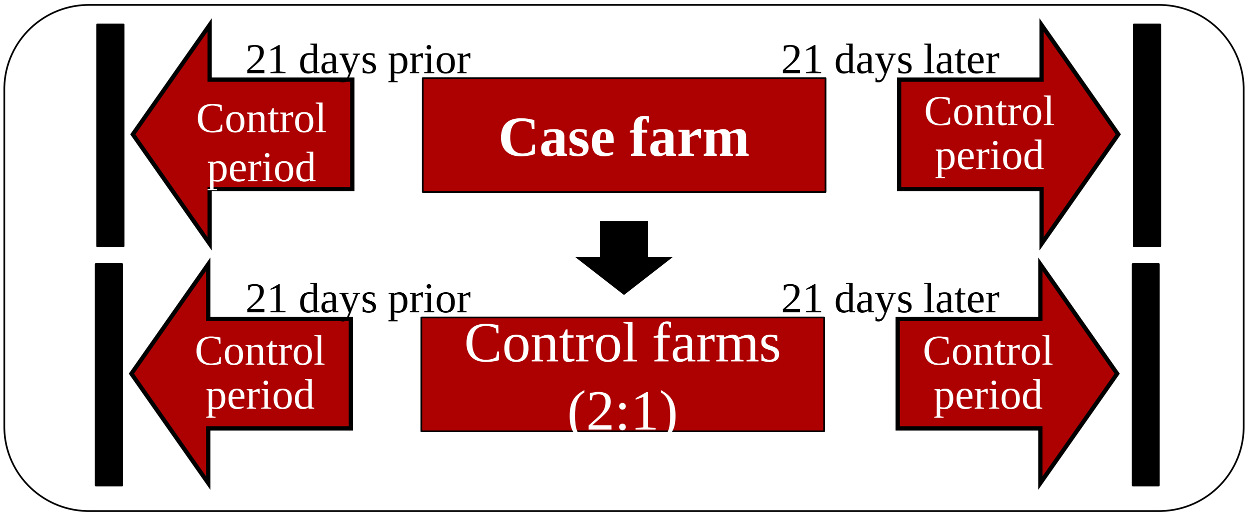

Fig. 3.1- Farm selection protocol for observational hybrid study design examining changes in on-farm mortality rate in dairy cows in Southern Ontario from 2010-2012.

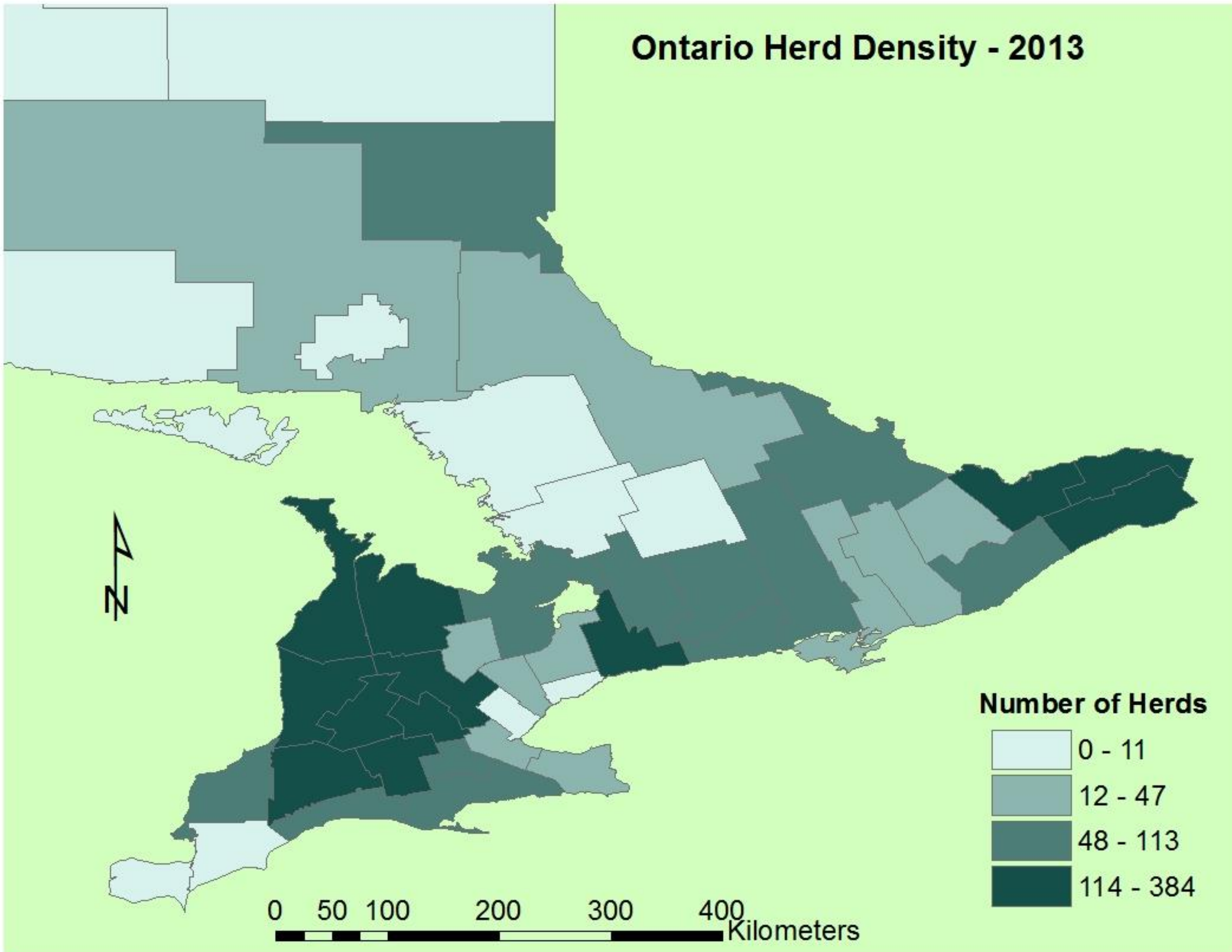

Fig. 3.2- Dairy cow farm density map. Total number of dairy farms per county.

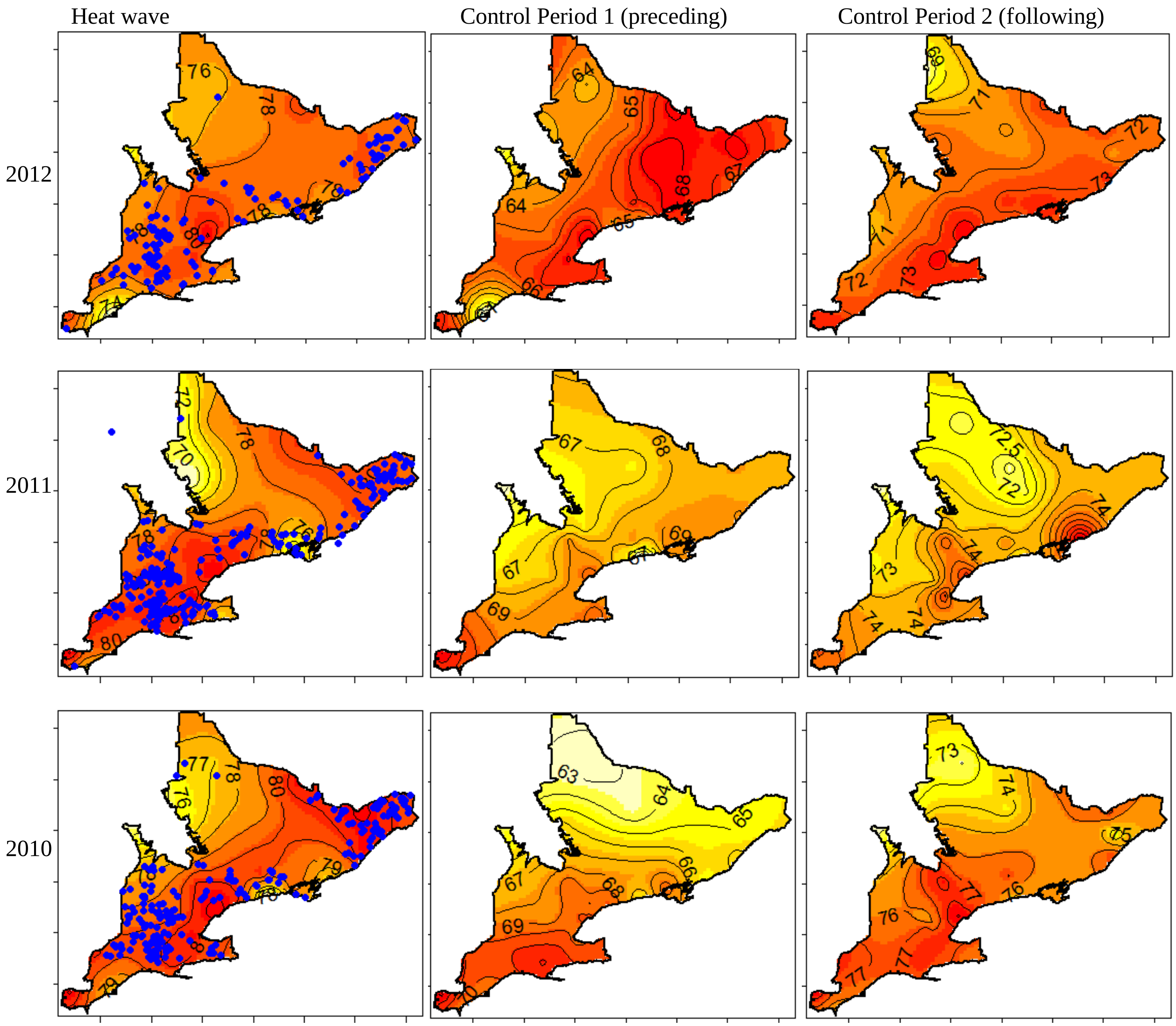

Fig. 3.3 - Heat stress maps for Southern Ontario during each of the 3 heat waves and 6 control periods with farm locations reporting deaths in that period marked in blue.

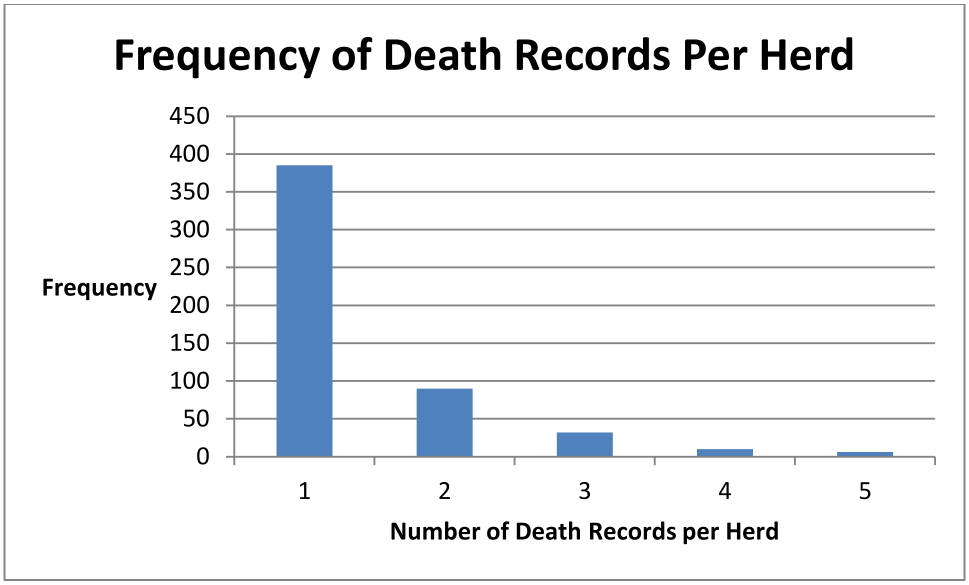

Fig. 3.4- Distribution of dairy cow death records per herd. (3 day data only)

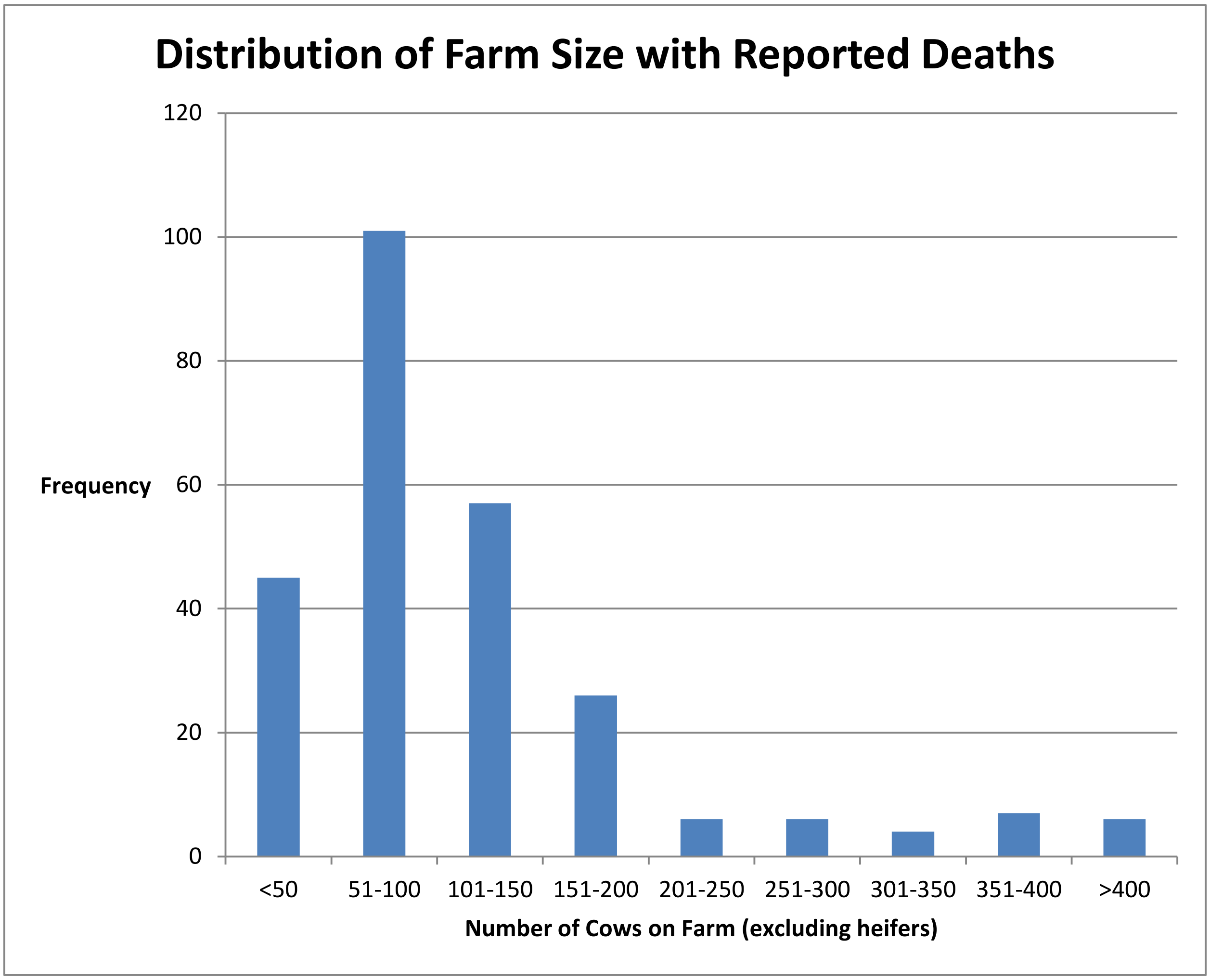

Fig. 3.5- Farm size for herds with reported deaths excluding heifers. (3 day data only)

Table 3.1- Dates of selected heat wave and control periods for Ontario from 2010-2012.

Year	Heat Wave Period	Control Period 1 (Preceding)	Control Period 2 (Following)
2012	June 19- 21	May 29- 31	July 10-12
2011	July 20-22	June 29- July 1	Aug 17-19
2010	July 5-7	June 14-16	July 26-28

Table 3.2- Number of farms reporting on-farm dairy cow deaths across Southern Ontario during each heat wave and the number of control farms for each year

Year	Heat wave	Number of Controls
2012	47	94
2011	126	252
2010	108	216

Table 3.3A- Univariable Analysis of On-farm Mortality Rate (Non-Spatial Poisson)

Parameter	Coefficient	IRR	95% CI	p-value
HSI	0.0287	1.03	1.025-1.035	<0.001
Cartesian Coordinates X	0.08070	1.084	0.019-0.147	0.0102
Y	-0.06658	0.9356	-0.236-0.102	0.4123

Table 3.3B- Multivariable Analysis of On-farm Mortality Rate (Quasi-likelihood Poisson)

Parameter	Coefficient	IRR	95% CI	p-value
HSI	0.3878	1.47	1.417-1.523	<0.001
(X,Y) Cartesian Coordinates	X= 0.04249	X= 1.04	0.980-1.010	X= 0.149
	Y= 0.06748	Y= 1.07	0.908-1.232	Y= 0.387

Table 3.3C- Final Model of On-farm Mortality Rate (Quasi-likelihood Poisson)

Parameter	Coefficient	IRR	95% CI	p-value
HSI	0.0287	1.03	1.025-1.035	<0.001

CHAPTER 4:

Heat Stress Related Emergency Room Visits in Rural Southern Ontario During Heat Waves.

***As prepared for submission to BMC Public Health**

Abstract

In Southern Ontario, climate change gave rise to an increasing occurrence of heat waves, causing heat stress to the general public, with potentially fatal consequences. Heat waves are defined as three consecutive days with temperatures of 32°C and above. Heat stress is the level of discomfort. A variety of heat stress indices have been proposed to measure heat stress (e.g., the heat stress index (HSI)), and has been shown to predict increases in morbidity and/or mortality rates in humans and other species. Maps visualizing the distribution of heat stress can provide information about related health risks and insight for control strategies. Information to inform heat wave preparedness models in Ontario was previously only available for major metropolitan areas.

Hospitals in communities of fewer than 100,000 individuals were recruited for a pilot study by telephone. The number of people visiting the emergency room or 24-hour urgent care service was collected for a total of 27 days, covering three heat waves and six 3-day control periods from 2010-2012. The heat stress index was spatially predicted using data from 37 weather stations across Southern Ontario by geostatistical kriging. Poisson regression modeling was applied to determine the rate of increased number of emergency room visits in rural hospitals with respect to the HSI. During a heat wave, the rate of emergency room visits was

1.11 times higher than during a control period (IRR = 1.11, $CI_{95\%}$ (IRR)= (1.07,1.15), $p \leq 0.001$). One high-risk cluster was identified in the southwestern portion of the study area by the spatial scan statistic during heat waves.

This finding will aid hospitals and rural public health units in preventing and preparing for emergencies of foreseeable heat waves. Future research is needed to assess the relation between heat stress and individual characteristics and demographics of rural communities in Ontario.

Keywords

Southern Ontario, Heat wave, Heat Stress, Rural Communities, Emergency Room

1. Introduction

Heat stress is a known health risk in major metropolitan areas around the world, including Southern Ontario (Kershaw and Millward 2012; Bassil et al. 2009; Pengelly et al. 2007; Smoyer-Tomic and Rainham 2001). Heat stress is the physiological response to extreme heat which can result in discomfort, morbidity and mortality. During periods of extreme heat such as heat waves, the likelihood of heat stress is increased. Environment Canada (2013) defines a heat wave as three consecutive days of maximum temperatures of 32 ˚C or higher. A heat stress index (HSI) can be used to quantify the level of discomfort an individual feels. A variety of HSIs have been developed, though in a comparison of these indices Barnett et al. (2010) illustrate that none of them is superior to the others. Therefore, Barnett et al. (2010) suggest choosing an HSI based on available data. Hartz et al. (2012) found in a study of the Chicago area that HSI is a better indicator of increase in predicted emergency room visits and 9-1-1 calls than ambient temperature. In Korea, Na et al. (2013) found that a temperature threshold was a better predictor of heat-related illness, where increases in the relative risk (RR) corresponded to increases in emergency room visits; however, their threshold of 31.2 ˚C (i.e. 88˚F) is slightly lower than the heat wave definition established by Environment Canada (2013).

Heat waves are an ideal period to study heat stress in Southern Ontario because a heat wave is illustrative of the effects of prolonged exposure to extreme heat (Rocklov et al. 2012). A study in Sweden found that excess mortality due to heat stress increased 2.0-3.9% per day (Rocklov et al. 2012). In Korea, estimates suggest that mortality increases 4.1% during heat waves (Son et al. 2012). Many simulations and models predict the increase of frequency, intensity and duration of heat waves in the future (Meehl and Tebaldi 2004; Wilhelmi et al. 2004). This increase will result in an increased public health burden for communities across Ontario, and likely throughout all of Canada. In Southern Ontario, there have been one or more heat waves each summer since 2003 (Environment Canada 2013).

While data are available to illustrate the current presence of heat waves in Southern Ontario, little is known about the impact these have on the population. Heat stress studies and their associated impacts are common for major metropolitan areas around the world such as Athens (Keramitsoglou et al 2013), Shanghai (Tan et al. 2007), Paris (Laaidi et al. 2012), Sydney (Schaffer et al. 2012) and Madrid (Linares and Diaz 2008). Studies of heat stress in the neighbouring United States of America indicate the presence of heat wave threats in North American cities such as Chicago (Whitman et al. 1997), Baltimore (Huang et al. 2011), and St. Louis and Kansas City (Jones et al. 1982). Studies of Canadian metropolitan area heat stress and its impacts illustrate the real threat of heat waves in cities like Montreal (Price et al. 2013) and Toronto (Kershaw and Millward 2012; Bassil et al. 2009; Pengelly et al. 2007; Smoyer-Tomic and Rainham 2001).

In contrast to urban settings, studies in rural areas are scarce. However, Martinez Navarro et al. (2004) report that the impact of heat waves on mortality could also be seen in rural communities in Spain. Furthermore, in Chapter 3 it was established an increasing dairy cow mortality rate in relation to heat stress for Southern Ontario.

Previous population based heat stress studies applied a variety of proxy measures to establish a link between heat waves and heat-related illness. Weather data have been collected by satellite imaging (Kershaw and Millward 2012) or from nearby weather stations (Theoharatos et al. 2010). Although these measures can provide a detailed image and understanding of the spatial distribution of heat stress in an area, there are two major drawbacks to using satellite imaging for this study. Satellite images are generally only available 1-2 times per day, which may not include the daily maximum or minimum heat stress level for a region on a given day (Maloley 2009). Furthermore, satellite imaging does not correlate to ambient temperature in rural communities as well as meteorological station measurements do, as a result of the amount of green space in the region (Maloley 2009). Health data have also been collected by a variety of proxy measures. Various data sources have been investigated such as 9-1-1 dispatch data (Kershaw and Millward 2012; Williams et al. 2011), emergency room visits (Jones et al. 1982), death records (Martinez Navarro et al. 2004), surveillance data (Na et al; Lowe et al. 2010), or a combination of the above (Schaffer et al. 2012). Increases in myocardial infarction and other circulatory disorders, respiratory disorders as well as falls and respective injuries are all known to be associated with extreme heat, which may be missed when only specific illness are considered (Linares and Diaz

2008). Moreover, the risks of illness or injuries as a result of heat stress are compounded for those who are obese, or with pre-existing cardiovascular disorders, respiratory disease and diabetes mellitus (Semenza et al. 1996). These indirect results of heat stress would not be documented as heat-related illness, but may be an indication that stress is high in the community.

The media can have a substantial impact on the health outcomes of a community during a heat wave. In New York City, heat wave warning systems were analyzed and compared to see which system for reducing mortality due to heat waves was the most effective (Metzger et al. 2010). The researchers determined that systems which warn local residents of a heat wave based on the daily maximum temperature had the greatest ability to reduce mortality (Metzger et al. 2010). No such studies exist for rural communities at this time.

According to projections for future climate change, heat waves are anticipated to increase in frequency, intensity and duration (Meehl and Tebaldi 2004; Wilhelmi et al. 2004). The public health burden associated with heat waves and heat stress is anticipated to increase as well (Peng et al. 2011). Peng et al. (2011) predicted that increases in extreme heat as a result of heat waves will cause excess mortality of 166-2,217 deaths per year by the year 2081 in Chicago. Moreover, Josseran et al (2009) found that the public health burden associated with specific ailments such as dehydration, hyperthermia, malaise, hyponatremia, renal colic and renal failure increase during heat wave events. To date, few studies have demonstrated if similar health issues arise in rural communities or if the magnitude of these relationships differs.

Heat stress distribution in Southern Ontario is stable over time (Chapter 2), and thus is predictable during a heat wave. In general, heat stress is high in and around major metropolitan areas such as the Greater Toronto Area (GTA). In Southern Ontario, heat stress was also high in the southwestern region surrounding London and in the east near Ottawa (Figure 4.1).

The goal of this study was to investigate whether heat waves pose a public health threat to residents of Southern Ontario using retrospective analysis of rural hospital emergency rooms visits during heat waves from 2010-2012. Specific objectives are: (i) to identify the levels of heat stress experienced by rural communities of Southern Ontario during a heat wave; (ii) to determine if heat waves have a significant impact on the number of visits to rural hospital emergency rooms; and (iii) to identify areas of high-risk for heat stress related illness in Southern Ontario.

2. Materials and Methods

2.1 Study area and population

Weather data for the region of Southern Ontario were collected in its entirety, defined by the public health units of Ontario's definition of Southern Ontario. The study area is home to nearly one third of the Canadian population and borders the St. Lawrence River, Lake Ontario, Lake Erie, and the southern portions of Lake Huron and Georgian Bay. This study area is thus quite different from areas investigated in previous work because it is substantially larger than most preceding heat stress map regions. Communities were defined as rural if the population of the town for the hospital mailing address was fewer than 100,000 people. A total of 61 communities with hospitals qualified for the study. Of 50 hospitals with emergency rooms contacted, 24 hospitals provided data for the number of visits to the emergency room for pre-specified dates.

2.2 Data Collection

Heat waves were identified using a search of the popular press which indicated possible heat wave dates. As a result of the variability in definitions for a heat wave, each heat wave was confirmed to meet the Environment Canada definition of a heat wave (3 days of temperatures of at least 32°C) at a minimum of 3 weather station locations in Southern Ontario. Control periods were selected based on dates of confirmed heat waves to start 3 weeks (21 days) prior to the start of the heat wave and 3 weeks following the start of the heat wave. Control periods were matched for day of the week to control potential weekday effects.

Weather data for this study were previously collected as part of another study (Chapter 2). Briefly, weather data were collected from the Environment Canada database, the National Climate Data and Information Archive (Environment Canada 2013), from 37 hourly operating weather stations on 27 dates.

A list of hospitals in Southern Ontario was obtained from the Ontario Hospital Association (2013). Hospital addresses were extracted from this database and the population of the town was retrieved from Statistics Canada (2013). Hospitals were contacted by telephone between October 16th, 2013 and November 25th, 2013. A short script (1-2 minutes, Appendix A) was used to inform hospital contacts of the nature of the request. A written data request was made to the Health Records Departments of the hospitals, after contact had been established by phone. The raw number of visits to the ER for non-scheduled appointments during a three day heat wave or control period was requested for a total of 9 periods (outlined in Table 4.1). Data collected from hospitals included the population of the community in which the hospital was located, number of emergency room visits per day and the method for record keeping at the hospital (see Appendix B).

For this pilot study, emergency room visit numbers were collected without personal identifiers to determine if heat stress was an existing problem in rural communities in Southern Ontario. When using emergency room data, all visits to emergency rooms were compared between heat waves and control periods. Control weeks were determined as being 3 weeks (i.e. 21 days) prior to and following respective heat waves, matched for day of the week bias. To illustrate the increase in morbidity rates during periods of extreme heat exposure ER admissions for all reasons were assessed. The Research Ethics Board at the University of Guelph did not require ethics approval for this study.

2.3 Mapping

The HSI defined by Johnson and Vanjonack (1976) was used in this study:

$$HSI = T_{DB} + (T_{DP} * 0.36) + 41.5$$

where T_{DB} and T_{DP} denote dry bulb temperature and dew point temperature respectively. All temperatures are measured in degrees Celsius. The HSI was calculated for each of the 37 weather stations as a 3-day average of the daily maxima. Geostatistical kriging was used to predict the spatial pattern of heat stress for the entire study area, (i.e., Southern Ontario). The HSI value for each hospital during the heat wave and control periods was determined using the same geostatistical model.

2.4 Modelling and Analysis

The average number of emergency room visits per day was calculated by the average of each of the three days of a heat wave or control to reflect the calculation of the HSI average over the 3-day period. Each period was dichotomized as a heat wave or control period for analysis.

A backwards stepwise procedure was used to build the Poisson regression model. A univariable analysis was done to screen for potentially significant variables at a liberal $\alpha = 0.2$. Northing, easting, and the dichotomized heat wave indicator were initially modeled. The least significant predictors were removed consecutively until all remaining parameters in the model were significant. Appropriate diagnostics were used to determine the quality of the fit of the model. Goodness of fit was assessed using a quantile-quantile plot of Anscombe residuals.

All spatial analyses were performed in R computing software version 3.1.0 (R Development Core Team, 2013), using a significance value of $\alpha = 0.05$ unless otherwise stated.

To test for areas of high or low risk, a spatial scan test was conducted for Southern Ontario to determine if areas were at increased risk of heat stress. The incidence rate ratio (IRR) was estimated in SaTScan by inputting the number of emergency room visit records per hospital and the population of the community. Spatial coordinates in latitude and longitude were translated to Cartesian coordinates in Universal Transverse Mercator (UTM) 17 North for analysis. A purely spatial model (i.e. no temporal analysis) using the Poisson distribution was used to test for clusters of high or low incidence of emergency room visits. Since the distribution of heat stress in Southern Ontario was previously shown to be stable (Chapter 2), all data for the 9 periods were used together to increase power for the scan test. Analysis was conducted in SaTScan vs 9.3 (Kulldorff et al. 2014) using a significance value of $\alpha = 0.05$, 999 Monte Carlo permutations and a maximum scanning window of 50% of the population. The p-value was estimated using the standard procedure in SaTScan. A space-time scan was not conducted because the heat stress distribution pattern in Southern Ontario is stable during heat waves (Chapter 2).

3. Results

3.1 Descriptive Results

Weather data were available from 37 weather stations across Southern Ontario, illustrated in Figure 4.1. The HSI at each weather station was estimated for every hour of available data. The maximum daily HSI value occurred most frequently between 12:00 and 15:00 (58%), and least often between 04:00 and 07:00 (0.4%).

The response rate for this study was 48%. Of a total 50 rural community hospitals in Southern Ontario which are located in towns of fewer than 100,000 people and which had an emergency room or 24-hour urgent care centre, 24 hospitals were willing to participate. The average population of the towns from which these hospitals come is 16,324 people (range: 2,579 – 83,575). Hospitals that participated in the study were primarily located in southwestern Ontario and in the Thousand Islands area along the St. Lawrence River (see Figure 4.2).

Heat stress maps were created previously for Southern Ontario (Chapter 2). Heat stress maps of the three heat waves and six control periods are depicted in Figure 4.3. These heat stress maps also illustrate the location of the 24 hospitals which were enrolled in this study. Heat stress follows a predictable pattern over space and time during a heat wave in Southern Ontario. Heat stress is highest in the southern portion of the study region, particularly concentrated around the Greater Toronto Area, and in a belt stretching from Lake Ontario to Lake Huron. The average onsite HSI at the 24 hospitals during a heat wave was 79 (range: 76-82), and during a control period the average onsite HSI at the 24 hospitals was 71 units (range: 64 – 78).

The average number of hospital visits to these emergency rooms during a control period was 61 emergency room admissions per day (range: 18 – 182). The average number of emergency room visits per day during a heat wave period was 63 (range: 21-174).

3.2 Analytic Results

The Poisson regression model was built using backwards stepwise modelling. A dichotomized heat wave variable, northing, and easting were significantly associated with the likelihood of having increased emergency room visits in univariable analysis. In the final model, the heat wave variable was the only significantly associated parameter with emergency room visits. The Akaike Information Criterion (AIC) was used to assist in selecting the best model. The incidence rate of emergency room admissions was 1.11 times higher ($CI_{95\%}$ (IRR) = (1.07, 1.15), $p \leq 0.001$) during a heat wave than during a control period. In addition to model comparison by AICs, a Quantile-Quantile plot of the residuals was visually inspected for indications of serious model inadequacies.. The q-q norm test was inspected for indications of serious model inadequacies, but none were detected. One hospital was identified as an outlier in this data set and did not fit the model well. This hospital was busier than the other rural hospitals in Southern Ontario.

One significant high-risk cluster of emergency room visits to rural hospitals in Southern Ontario was detected using the spatial scan test ($p \leq 0.001$) during heat waves. The cluster is located in the southwestern portion of the study region with a radius of 96 kilometers (Figure 4.4, Table 4.2). The relative risk (RR) within the cluster is 3.8 times higher ($p \leq 0.001$) than the risk outside the cluster. No high or low risk clusters were identified during control periods ($p > 0.05$).

4. Discussion

From this study it is apparent that heat stress is a current and could be a growing problem for individuals in rural communities in Southern Ontario. Although heat stress is commonly considered a problem for cities, as a result of urban heat islands, it is clear that heat stress is also a problem in small towns and communities. Mapping of heat stress in relation to rural hospitals and Poisson regression models of rural emergency room visits illustrate the increased risk of injury and illness during periods of extreme heat outside of the urban heat island as well. It is also reasonable to argue that many people in cities are less affected by the heat as they are more likely occupied by indoor jobs. In contrast, it is more likely that people residing in rural communities have jobs which require them to spend extended periods of time outside.

The impact of heat wave related morbidity in Southern Ontario is substantial in the grand scheme. The increase of 2 hospital emergency room visits per day per rural community hospital suggests an increase during a 3-day heat wave of 6 visits, which at 50 rural hospitals in Southern Ontario amounts to 300 excess admissions to the emergency room per heat wave in rural areas.

The results of the scan test suggest that the southwestern area of the study region, near Lake Huron, are at increased risk of heat related morbidity resulting in emergency room visits than the surrounding study region. This result coincides with being an area previously recognized for its high levels of heat stress during heat waves (Chapter 2).

In rural communities, the catchment area of a hospital is often much larger than that of a hospital in a city. This may impact the results of the study, as the HSI predicted at the hospital may not accurately represent the HSI predicted at the individual's location at the time of onset of illness. However, based on the maps of heat stress distribution presented in this study, it appears that neighbouring towns experience a similar HSI at any given time. By taking 3-day averages, there may be a smoothing effect, not just in time, but in space as close things are more related than distant things (Tobler 1970). Therefore, temporal averaging may imply spatial smoothing. This may also have impacted the ability to detect a cluster of high or low risk for emergency room visits.

This study utilized preliminary data without personal identifiers or information about the activity which patients were participating in at the time of injury or onset of illness. It is possible that risky behaviours which are associated with heat but not caused by heat also increased. Such activities as boating which may result in drowning or swimming which may result in slips or injury are likely more common during extreme heat, and thus may inflate the number of hospital visits. This may indicate a possible confounder which over estimates the effect of heat stress on morbidity.

Although an HSI that is generally used in animal populations was applied here to a human population to predict the heat stress distribution across the study region, the maps are predictive of heat stress distribution in humans for Southern Ontario. Barnett et al. (2010) tested 5 different HSI estimators with data from 105 cities, and determined that HSI estimators are equally predictive when used correctly. It is therefore best to use the HSI estimator for which there is least missing data. The hourly weather station data retrieved from Environment Canada (2013) provided complete recordings for both dry bulb temperature and dew point temperature, as required to estimate the Dairy Cow HSI. Moreover, the Dairy Cow HSI does not use dairy physiology measures to estimate discomfort, but is based solely on environmental factors.

The model built for these data does not fit observations from one of the 24 hospitals well. This particular hospital is much busier than the other hospitals investigated in this study. It is possible, that this hospital is busier because it attracts the population in the neighbouring city catchment during summer months. This hospital is located in an area which is known to be more highly populated during the summer, particularly as travellers pass through toward the Ontario cottage districts. There are no data to confirm this hypothesis; however, it is speculated that a portion of local residents may come to this hospital from the city to avoid traveller congestion along the major summer travel routes. This hospital was not located within the high-risk cluster.

This pilot study illustrated an existing problem of heat-related morbidity in Southern Ontario, for which future surveillance systems may be useful. This study, which is the first of its kind in Southern Ontario, may be used by rural public health units to assess the risk of heat-related morbidity during periods of extreme heat. In many large cities in Southern Ontario, there are cooling centre strategies for heat waves. This study may encourage smaller communities to develop similar strategies. In Southern Ontario, these programs are run at the local level, and may include such things as building cooling centres, water stations along busy pedestrian paths or media alerts. Philadelphia researchers estimate that cooling centres saved 117 lives within the city in 3 years from 1995-1998 (Eli et al. 2004).

5. Conclusion

The rate of increased rural emergency room visits is 1.11 times higher during a heat wave than during a control period. This is a problem across Southern Ontario; particularly in areas, such as southwestern Ontario, that the heat stress maps indicate are at increased risk of heat-related morbidity and where a high-risk cluster was identified. As the impact of heat waves increases in frequency, intensity and duration, the public health burden associated with heat waves will also increase. The results from this study should mobilize rural public health units in Southern Ontario to develop heat stress prevention programs (e.g., by implementing cooling strategies or media alerts during heat waves).

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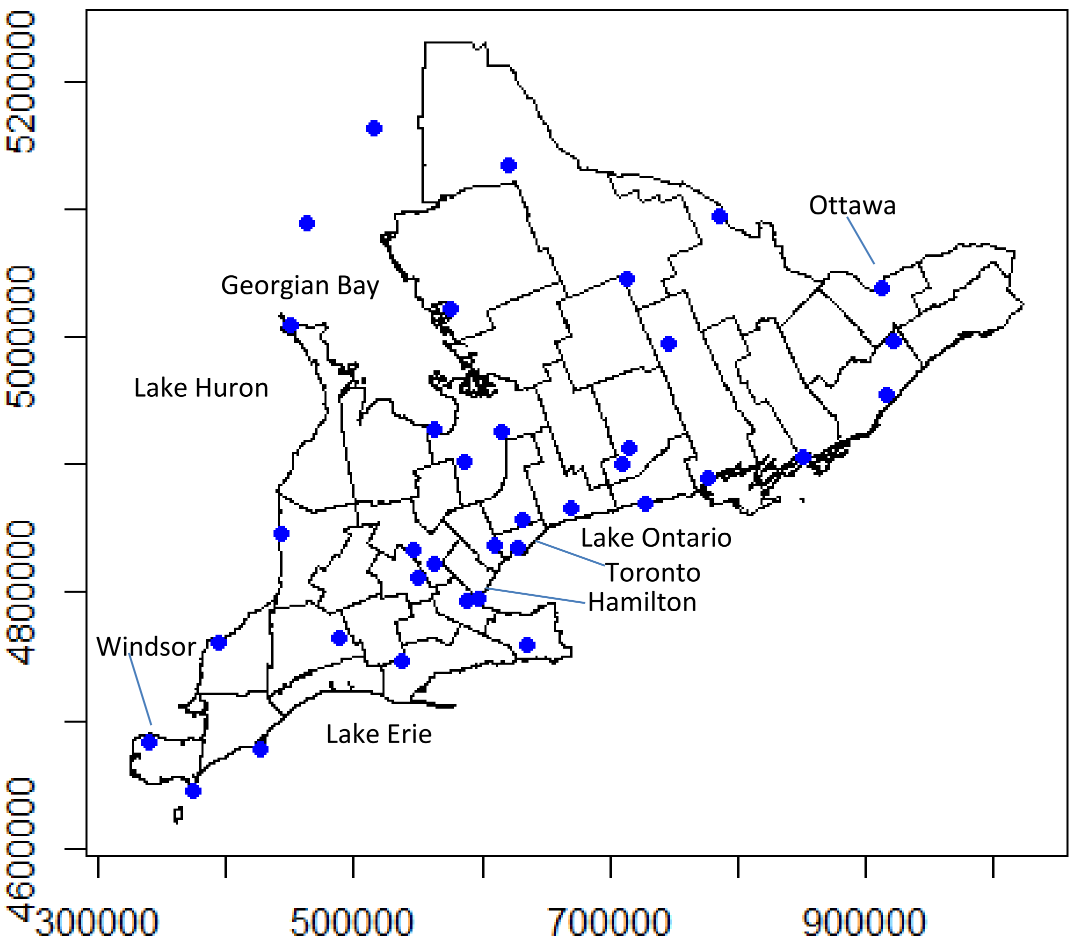

Fig. 4.1- Location of meteorological stations. Locations of 37 meteorological stations in and around Southern Ontario which provide hourly interval data collection. Axis units are in meters.

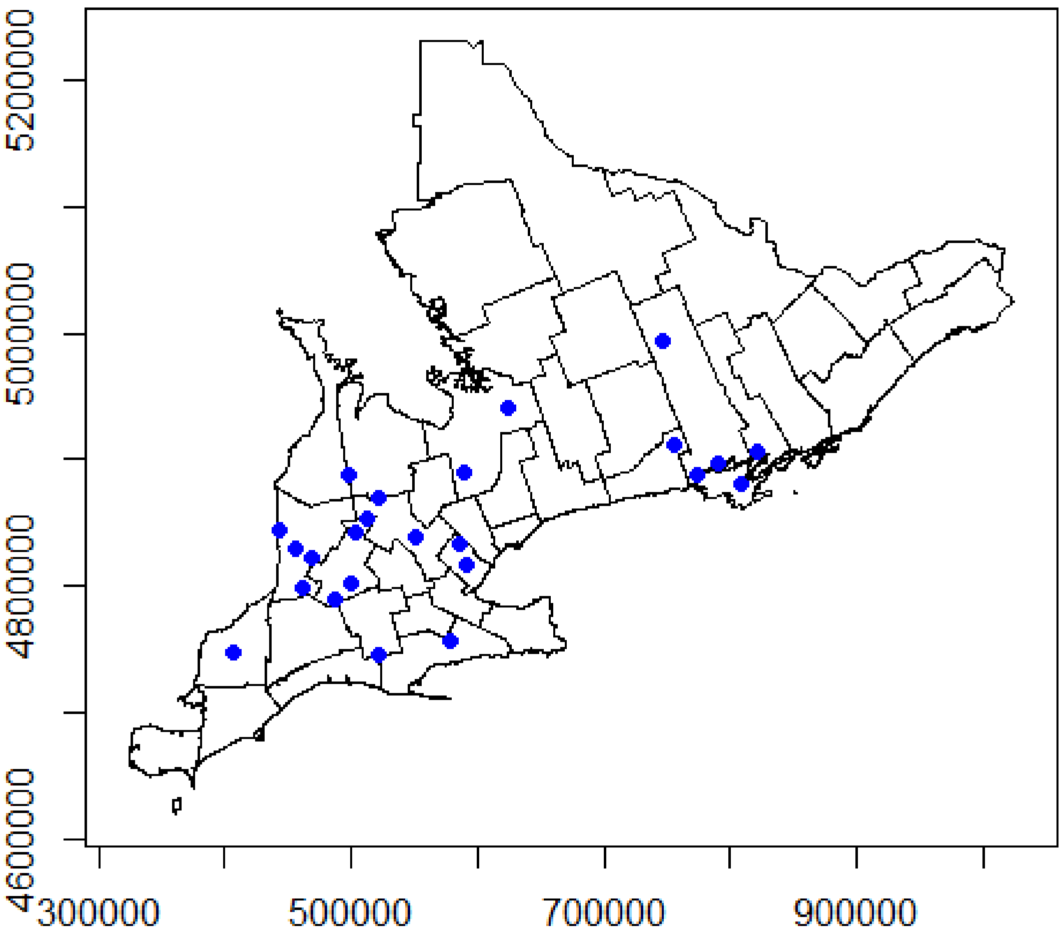

Fig. 4.2- Location of participating hospitals. Locations of 24 rural community hospitals in Southern Ontario which provided data for the number of emergency room visits per day for a study from 2010-2012. Axes units are in meters.

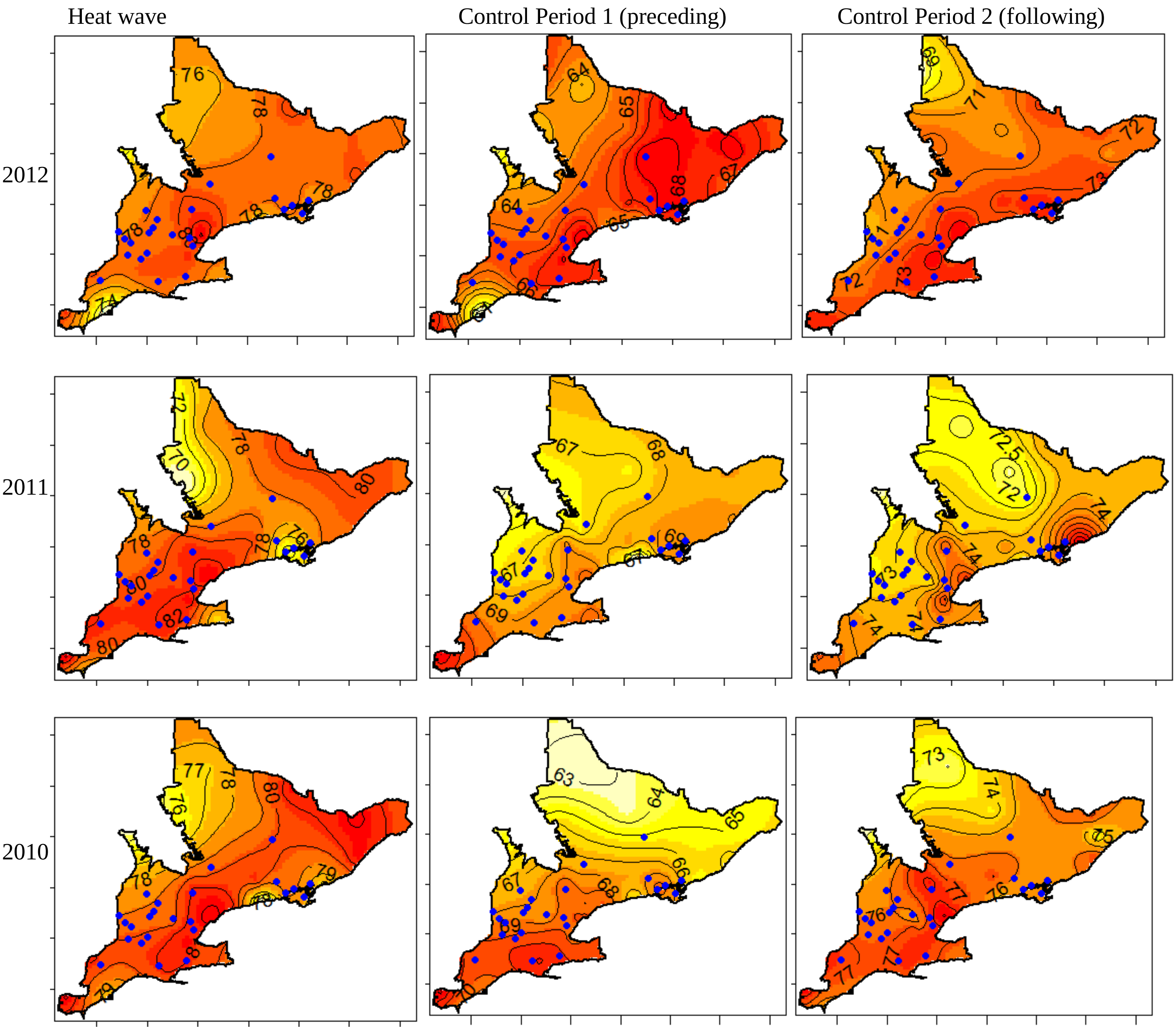

Fig. 4.3- Heat stress maps for Southern Ontario during each of the 3 heat waves and 6 control periods with hospital locations marked in blue.

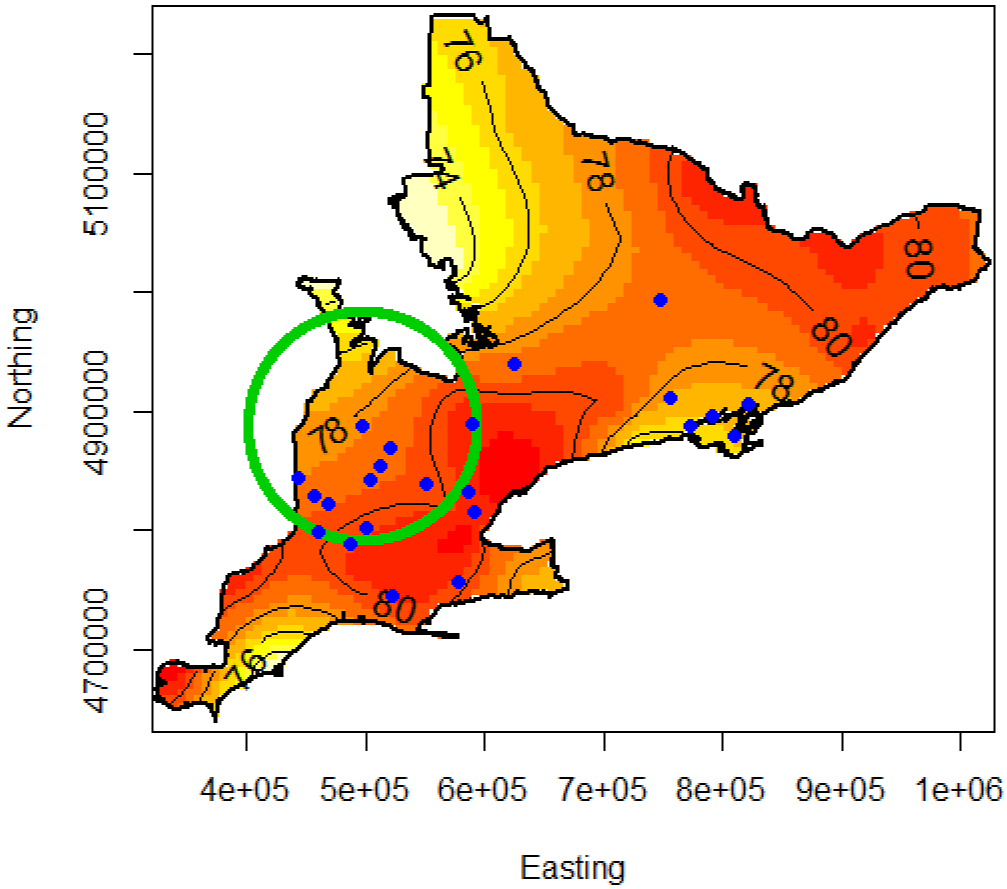

Fig. 4.4 Location of high risk cluster for heat related morbidity during all 3 heat waves where the area enclosed in the circle marks an area of increased risk of heat related morbidity resulting in emergency room visits. The locations of 24 rural community hospitals in Southern Ontario marked in blue. Axes are in meters.

Table 4.1- Dates of selected heat wave and control periods for Ontario from 2010-2012.

Year	Heat Wave Period	Control Period 1 (Preceding)	Control Period 2 (Following)
2012	June 19- 21	May 29- 31	July 10-12
2011	July 20-22	June 29- July 1	Aug 17-19
2010	July 5-7	June 14-16	July 26-28

Table 4.2- High risk cluster for increased emergency room visits during heat waves in rural Southern Ontario from 2010-2012.

	Inside the Cluster	Total Area
Population	75,280	390,462
Number of cases	6,583	13,838
Annual cases /100,000	8,726	3,537
Relative Risk (RR)	3.8 times higher	(ref)
Size (Radius)	96 km	
P-value	< 0.001	

CHAPTER 5:

Discussion, Limitations, Future Directions and Conclusions

DISCUSSION

This thesis presents evidence for the current impact of climate change on health in Southern Ontario. Firstly, maps illustrating the distribution of heat stress in Southern Ontario were produced by geostatistical kriging and illustrate the spatial distribution of heat stress during heat waves and control periods, represented by the Dairy Cow Heat Stress Index (HSI; Johnson and Vanjonack 1976) (Chapter 2). Subsequent chapters used these heat stress distribution maps in Southern Ontario to investigate the relation between heat stress and a medical event or death.

In Chapter 3, heat stress was predicted from weather station locations to farm locations for heat wave and control periods. The study followed a risk-based retrospective hybrid study design. As heat stress increased, the mortality rate of dairy cows on farm increased 3% ($CI_{95\%}$ (IRR)= (1.025,1.035), $p \leq 0.001$) per one unit increase in HSI (Chapter 3). With an average HSI increase during a heat wave of 8.6 units (HSI of 71 units during a control period and an HSI of 79 units during a heat wave), the mortality rate increases 27% on average during a heat wave and results in approximately 26 excess deaths per 3-day period across Southern Ontario.

In the third project (Chapter 4), the HSI at the location of rural community hospitals during heat waves and control periods was linked with the number of emergency room visits. Rural hospitals had on average 1.11 times higher incidence rates of visits to the emergency room during heat waves, compared to control periods ($CI_{95\%}$ (IRR)= (1.07,1.15), $p \leq 0.001$). During a heat wave there was an average increase of 2 emergency room visits per day per hospital. With 50 rural hospitals in Southern Ontario, a 3-day heat wave would likely result in 300 excess hospital admissions across the region. A high-risk cluster for increased emergency room visits during heat waves was identified in the southwestern portion of the study region. The relative risk of increased emergency room visits during heat waves within the cluster was 3.8 times higher than that outside the cluster. The cluster was identified in the same area of the study region as an area of high heat stress.

This chapter aims to describe and synthesize the common themes that warrant further discussion: the impact of increasingly frequent, intense and longer lasting heat waves and the issues surrounding community or farm preparedness for future heat waves.

Heat waves of increasing frequency, intensity and duration

It is generally accepted that heat waves are one of a number of extreme weather phenomena which, due to climate change, will increase in frequency, intensity and duration in the future (Meehl and Tebaldi 2004; Wilhelmi 2004; McMichael et al. 2006; Haines et al. 2006). Predictions range from increases of 27 hot days per year (Solymosi et al. 2010) to as much as a 5.8 ˚C annual average temperature increase by the year 2100 (IPCC 2001). Despite variability, these predictions are unanimous in directionality. With increased heat waves and relative heat stress, the impacts on dairy cattle survival (Vitali et al. 2009) and on human health (Peng et al. 2011) may be substantial.

At the farm level, increases in frequency, intensity and duration of heat waves are suggestive of increases in on-farm mortality, decreased animal welfare and decreased productivity. The economic losses of farmers in Southern Ontario will be exacerbated beyond the loss of a single cow as heat stress may decrease the quality and quantity of milk produced on the farm (Reiczigel et al. 2009). The welfare of cows in Southern Ontario during the hot summer months will be a growing concern for farmers and researchers alike.

From a human health perspective, increases in heat waves in Southern Ontario will be suggestive of increased morbidity and hospitalization in rural populations. Other studies even report excess mortality in human populations. The increase in hospitalizations has economic impacts through direct medical costs and lost working days (Fortune et al. 2013).

Heat wave preparedness

While it is concluded here that heat waves are an emerging problem in Southern Ontario, there is little evidence of community preparedness to handle these weather emergencies. It may be said that the issue of heat waves is not even recognized which is a mindset that prevents the discussion of preparedness from occurring. Economic losses in livestock and human medicine alike can be mitigated with effective preparedness plans, and even reduce the mortality rate due to a heat wave (Metzger et al. 2010). Moreover, research determined that systems which warn local residents of a heat wave based on the daily maximum temperature had the greatest ability to reduce mortality (Metzger et al. 2010).

On farm, heat abatement strategies are essential to maintain production, ease discomfort, lessen mortality and improve welfare of dairy cows during extreme heat (Collier et al. 2006). It has been shown that the intensive use of effective heat abatement strategies can reduce production losses due to heat by as much at 25% (St. Pierre et al. 2003). Options for heat abatement plans on farm include wetting, wind tunnels, fans and misting systems among others (Collier et al, 2006). Policy changes in the dairy farming community which devise plans for information sharing during a heat wave may have dramatic impacts on dairy cow survival during a heat wave. The heat wave induced heat stress dairy cow mortality rate can be reduced by establishing a warning system which encourages the intensive use of heat abatement strategies.

Rural communities have been previously neglected in the growing wealth of knowledge regarding climate change and public health. Substantial research has been done in Canadian metropolitan areas (Kershaw and Millward 2012; Bassil et al. 2009; Pengelly et al. 2007; Smoyer-Tomic and Rainham 2001; Price et al. 2013), however, this project was the first to focus on heat stress in rural areas of Canada. This research justifies the need for community preparedness plans for heat stress in rural Southern Ontario, not only in major cities. Many cities within the study boundaries employ plans for extremely hot weather, but these actions are uncommon in rural communities. Policies such as heat alerts, cooling facilities and drinking water stations have proven successful in metropolitan areas (Martinez et al. 2011).

LIMITATIONS

A variety of study limitations should be considered for this thesis, including data availability, spatial resolution and accuracy and the inclusion of a pilot study. Firstly, data available for hourly weather station recordings in Southern Ontario were available at only 37 stations across Southern Ontario. While this resolution was sufficient to produce heat stress maps, there is a possibility that localized weather phenomena, such as a thunder storm between stations, were missed. The use of three day average maximum values reduces the impact these extreme localized events would have on the data quality, yet their true impact is not entirely known. Secondly, a variety of data proxy measures were required to carry out this project. As no measure of heat related illness is available from hospital records and the potential for skewed data which records heat related health emergencies as a secondary cause for hospital admission, it was necessary to collect the total number of admissions to hospital emergency rooms and compare these to the respective number for a control period. A longitudinal study which follows a number of hospitals through control and heat wave periods, specifically recording data for heat related illness and exact location at time of onset will have improved validity over this study. In both the dairy cow mortality study and the human emergency room visit study, spatial resolution is not perfect. In the dairy cow mortality study, heat stress is predicted to the farm's barn door, which may not entirely reflect the HSI felt by the cows inside the barn. It is likely this value underestimates the HSI the dairy cows feel in the barn as the HSI outside the barn is expected to be approximately 11 units lower at any given time (Schüller et al. 2013). In the hospital emergency room admissions study, the accuracy of the HSI estimate is slightly less reliable as a result of the level of information collected. As no personal identifiers were collected about patients admitted, the HSI level predicted is to the hospital's location. This may not represent the level of stress the individual was under when they fell ill and went to the hospital. Finally, the hospital emergency room visits is the first of its kind in Canada, and thus is only a starting point for further research. For this project, no personal identifiers were needed to calculate incidence rate ratios and perform Poisson regression; however, in future studies this data would likely be useful to understand individual risk factors for heat-related illness.

FUTURE RESEARCH

Based on research conducted for this thesis (Chapters 2-4) and the synthesis of information in the literature review and discussion (Chapters 1 and 5), the following outlines a number of questions for future research.

- **Knowledge transfer and translation (KTT):** The real-world application of the results from this thesis should be shared with those who can most benefit from this information. Results should be shared with researchers through conferences and publication, with policy makers via plain language policy briefs and conference presentations which inform of the need for policy in both agriculture and rural communities with regards to heat stress and heat wave preparedness, and farmers and rural community citizens via media releases or plain language results sharing meetings across the region. Evaluations of the effectiveness of such KTT methods would be beneficial for future endeavors.
- **Policy change and evaluation:** While KTT is an active starting place for effective policy change, it is not sufficient to make change happen. Research which highlights the impacts of heat wave preparedness policy and evaluates the effectiveness of such programs is essential for substantial buy-in. The comparison of existing heat wave preparedness

programs in a sample of communities throughout rural Southern Ontario could be the basis for a program evaluation which is used to promote similar programming across the province.

- **Concerns for heat related health emergencies in other species:** In other Canadian provinces (e.g., Quebec), research has illustrated the impact of heat waves on livestock species such as pigs (D'Allaire et al. 2009). With the establishment of maps illustrating high levels of heat stress in Southern Ontario and the realization of health impacts of heat waves on both humans and dairy cows in the region, there is sufficient evidence to justify research studying the impact of heat waves in Southern Ontario on other livestock such as pigs and poultry.
- **Research related to heat abatement strategies during heat waves:** Research shows that heat abatement strategies can reduce productivity losses on dairy farms during heat waves (St. Pierre et al. 2003). In Southern Ontario it would be useful for farmers to know which heat abatement strategies are most effective, most efficient and which can best reduce the impacts of productivity loss and mortality on the economic state of the farm.

CONCLUSION

This thesis describes a study of heat stress distribution in Southern Ontario and the impacts of heat waves on the health of humans and dairy cattle. Empirical research results and information about areas of high risk for extreme heat stress, dairy cow on-farm mortality rates and hospital emergency room admissions are intended to impact policy and management practices which result in increased survival and decreased economic losses for farmers and the government. The synthesis of information contained in this thesis should encourage planning for heat wave preparedness programs in rural communities and on-farm. Heat wave preparedness programs will benefit public health including animal welfare. While this research highlights data from 3 years (i.e. 2010-2012), it also highlights the need for additional resource allocation (e.g., monetary, infrastructure etc.) to this problem at present and in future, and the need for further research to better understand the impacts of climate change in Southern Ontario and Canada.

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APPENDIX A

Hospital Phone Script

Good morning/afternoon. My name is Katherine Bishop-Williams, and I am a researcher and graduate student at the University of Guelph. I am interested in rural human health, and the effects of climate on the health of your community.

I am currently seeking data for the raw number of individuals who used your emergency room or urgent care facilities on a set number of days from 2010-2012. The data I am seeking is whole numbers only, and does not in any way connect to individual characteristics. This rural health analysis aims to show the relationship between extreme heat and urgent health care issues in Southern Ontario. Our hope is to increase awareness and funding for rural health programs and education related to heat stress. This project has been brought to the University of Guelph Research Ethics Board, and was granted to move forward without an ethics review because no personalized data is being collected for individuals.

The data you provide, should your hospital choose to participate, will be whole number of visitors only, and will be aggregated over 3-day intervals to mimic a heatwave or control period.

Do you have any questions at this time?

APPENDIX B

Hospital Data Collection Sheet

Hospital Name: ____

Hospital ID Number: _______

Hospital Address: ____

____

Hospital Telephone Number: ____________________________________

Date of Call: ______________________ Date of second call if needed:

____

Person spoken to: __________________________, Department: ______________________

Town Population: ___________________________

Screening Question 1:

Does your hospital have an Emergency Room or Urgent Care Centre? → answer must be yes

Screening Question 2:

Is the town where your hospital is located ________? → answer must be yes

Screening Question 3:

Is the population of ________ less than 100,000 people? → answer must be yes (confirmed against Statistics Canada data)

Question 1:

Does your hospital keep records of the raw number of ER/UCC visits? (If no, are they attainable in some way?)

Question 2:

How many people visited the ER/UCC, for any cause, on the following dates:

Year	Date	HSI Value	Number of Visits for any cause
2012	May 29		
2012	May 30		
2012	May 31		
2012	**June 19**		
2012	**June 20**		
2012	**June 21**		
2012	July 10		
2012	July 11		
2012	July 12		

Year	Date	HSI Value	Number of Visits for any cause
2011	June 29		
2011	June 30		
2011	July 1		
2011	**July 20**		
2011	**July 21**		
2011	**July 22**		
2011	Aug 17		
2011	Aug 18		
2011	Aug 19		

Year	Date	HSI Value	Number of Visits for any cause
2010	June 14		
2010	June 15		
2010	June 16		
2010	**July 5**		
2010	**July 6**		
2010	**July 7**		
2010	Aug 2		
2010	Aug 3		
2010	Aug 4		

Notes:

APPENDIX C

List of Hospitals Which Participated in Human Morbidity Study

Tilsonburg District Memorial Hospital
167 Rolph Street
Tillsonburg ON, N4G 3Y8

Listowel Memorial Hospital
255 Elizabeth Street East
Listowel ON, N4W 2P5

South Huron Hospital Association
24 Huron Street West
Exeter ON, N0M 1S2

Hanover and District Hospital
90-7th Avenue
Hanover ON, N4N 1N1

West Haldimand General Hospital
75 Parkview Road
Hagersville ON, N0A 1H

Stevenson Memorial Hospital
200 Fletcher Crescent
Alliston ON, L9R 1W7

Lennox and Addington County General Hospital
8 Richmond Park Drive
Napanee ON, K7R 2Z4

Alexandra Marine and General Hospital
120 Napier Street
Goderich ON, N7A 1W5

Headwaters Health Care Centre
100 Rolling Hills Drive
Orangeville ON, L9W 4X9

Milton District Hospital
7030 Derry Road
Milton ON, L9T 7H6

Georgetown Hospital
1 Princess Anne Drive
Georgetown ON, L7G 2B8

Groves Memorial
235 Union Street East
Fergus ON, N1M 1W3

Louise Marshall Hospital
630 Dublin Street
Mount Forest ON, N0G 2L3

Palmerston and District Hospital
500 Whites Road
Palmerston ON, N0G 2P0

Orillia Soldiers Memorial
170 Colborne Street West
Orillia ON, L3V 2Z3

Stratford General Hospital
46 General Hospital Drive
Stratford ON, N5A 2Y6

St. Mary’s Memorial Hospital
267 Queen Street West
St Mary’s ON, N4X 1B6

Clinton Public Hospital
98 Shipley Street
Clinton ON, N0M 1L0

Seaforth Community Hospital
24 Centennial Drive
Seaforth ON, N7A 1W5

Charlotte Eleanor Englehard Hospital Bluewater Health
450 Blanche Street
Petrolia ON, N0N 1R0

Belleville General Hospital
265 Dundas Street East
Belleville ON, K8N 5A9

North Hastings Hospital
1H Manor Lane, P.O. Box 157
Bancroft ON, K0L 1C0

Prince Edward County Memorial Hospital
403 Main Street East
Picton ON, K0K 2T0

Trenton Memorial Hospital
242 King Street
Trenton ON, K8V 5S6