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Authors
Graham, Drew A
Vanos, Jennifer K
Kenny, Natasha A
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The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada

Drew A. Graham[a], Jennifer K. Vanos[b], Natasha A. Kenny[c], Robert D. Brown[d,*]

[a] *School of Environmental Design and Rural Development, University of Guelph, Guelph, ON, N1G 2W1, Canada*
[b] *Department of Geosciences, Texas Tech University, Lubbock, TX 79409, USA*
[c] *Taylor Institute for Teaching and Learning, University of Calgary, Calgary, AB T2N 1N4, Canada*
[d] *Department of Landscape Architecture and Urban Planning, College of Architecture 3137 Texas A&M University, College Station, TX 77843-3137, USA*

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ABSTRACT

Two thirds of Canadians reside in urban areas and 85% of recent population growth occurs in these areas. The intensity and duration of extreme hot weather events are predicted to increase in Canadian cities and in cities globally. It is well established that human suffering due to extreme heat is exacerbated in urban as compared to rural environments. Understanding the characteristics of urban landscapes that play the greatest roles in exacerbating the human health impact of extreme heat is thus imperative. This study explores the relationship between the amount of canopy cover from trees and the incidence of heat-related morbidity during extreme heat events in 544 neighbourhoods of Toronto, Ontario, Canada. Four extreme heat events from three years were studied. Heat-related ambulance calls were found to be 12.3% higher during the heat events than in the preceding or the following week. The number of heat-related ambulance calls was negatively correlated to canopy cover (Spearman Rank rho = −0.094, p = 0.029) and positively correlated to hard surface cover (Spearman Rank rho = 0.150, p < 0.001). Toronto neighbourhoods, as defined by Census Tracts, with less than 5% canopy cover had approximately five times as many heat-related calls as those with greater than 5% tree canopy cover, and nearly fifteen times as many heat-related calls as Census Tracts with greater than 70% tree canopy cover. These data suggest that even a marginal increase in the tree canopy cover from <5% to >5% could reduce heat-related ambulance calls by approximately 80%. These results have important implications for human health during heat events, particularly in the context of global climate change and urban heat islands, both of which are trending toward hotter urban environments in future.

1. Introduction

Between 2006 and 2011, 85% of population growth in Canada (1,589,378 people) occurred in urban areas (i.e. population >100,000) and these areas accounted for 69% of the total population (23,123,441 people) as of May 2011 (Statistics Canada, 2012b). The elevated rates of heat-related morbidity and mortality associated with urban, as compared to rural, environments (Smoyer et al., 2000; Luber and McGeehin, 2008; Canadian Institute for Health Information, 2011) provide a link between urbanization and human heat health.

Toronto, Ontario is Canada's largest city and also experiences the nation's highest frequency of extreme heat events (EHEs, also known as "heat waves") lasting two days or longer (Smoyer-Tomic et al., 2003). The frequency of EHEs is predicted to triple between 2005 and 2050 (Toronto Public Health, 2005; Environment Canada, 2005) and to quadruple by 2080 (Toronto Public Health, 2005). To date, the specific characteristics of Toronto's complex urban landscape that may play a role in human health impact of extreme heat have not been identified.

Exposure to extreme and/or prolonged heat can result in heat-related morbidity, which manifests as heat edema, heat rash (miliaria rubra), heat cramps, heat fainting (parade syncope), heat exhaustion, and/or heat stroke (Centers for Disease Control, 2006; Toronto Public Health, 2009b; Health Canada, 2011). If untreated,

* Corresponding author at: Department of Landscape Architecture and Urban Planning, College of Architecture 3137 Texas A&M University, College Station, TX 77843-3137, USA. Tel.: +1 979 8456 1019.
E-mail address: rbrown@arch.tamu.edu (R.D. Brown).

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damage to various internal organs, coma, and death can result (Centers for Disease Control, 2006; Luber and McGeehin, 2008; Toronto Public Health, 2009b). Morbidity (Semenza et al., 1999; Bassil et al., 2009; Bassil et al., 2011; Vanos et al., 2012a; Hartz et al., 2013) and mortality (Semenza et al., 1996; Smoyer et al., 2000; Toronto Public Health, 2005; Centers for Disease Control, 2006; Pengelly et al., 2007; Robine et al., 2008) specifically related to heat exposure have been reported in temperate regions across Europe and North America, including Toronto. Hartz et al. (2013) compared heat-related morbidity in Chicago, IL (temperate) and Phoenix, AZ (hot, arid). Larger spikes of heat-related morbidity occurred in Chicago as compared to steadier occurrences Phoenix, suggesting a degree of acclimatization in hot, arid environments that is not realised in more temperate regions (Hartz et al., 2013). From 1954–2000, 120 deaths per year in Toronto alone were attributed to heat exposure, a number that is expected to triple by the year 2080 (Toronto Public Health, 2005). Canada's urban-centric population and predictions of both increased EHE frequency and heat-related illness collectively support the need for improved understanding of the impacts of extreme heat and the urban landscape on human health.

Urbanization has resulted in significant modification of natural landscapes through the intensification of urban development—a change that has consequences for the regional climate and those living within the built environment (Georgescu et al., 2014). "Urban heat islands" (UHIs) describe the relatively greater temperatures of highly built urban environments versus rural areas (Oke, 1987; Luber and McGeehin, 2008; Stewart and Oke, 2009; Mohsin and Gough, 2010; Canadian Institute for Health Information, 2011). Urban heat islands commonly form in large built-up urban environments due to the high heat capacity of buildings and urban surfaces, as well as long wave radiation that is trapped and emitted by tall buildings, thus preventing heat loss from the urban canopy layer (Oke et al., 1991). This trapped heat causes the overheating of built features in urban landscapes and creates thermal discomfort and heat stress in humans populating these areas (Vanos et al., 2010).

Urban surface and air temperatures are intrinsically connected to many interrelated urban design features such as material use, landscape and building surface properties, orientation, sky view factor, and sun angle (Krayenhoff and Voogt, 2007; Yaghoobian et al., 2010; Ketterer and Matzarakis, 2014). The selection of surface cover (e.g., asphalt versus vegetation, trees versus open space design) tightly controls the resulting surface temperature and thus the overlying air temperature (Shashua-Bar et al., 2011) as well as canopy temperature when trees are present (Yaghoobian et al., 2010). Overheating and the significant variations of temperatures across a city are especially relevant during summertime EHEs (Harlan et al., 2006; Jenerette et al., 2011). On sunny, warm days, the exposure of the surface and humans to the mean radiant temperature – the combination of all short- and long-wave radiant fluxes (Thorsson et al., 2007) – becomes the most significant agent of heat gain (Johansson et al., 2014).

Open, un-shaded parks with high radiant heat loads are less conducive spaces for safe physical activity and thermal comfort (Matzarakis and Endler, 2010; Vanos et al., 2012a). Hence, the design choice of an urban area can either support or diminish the long-term health and resilience of a city and its inhabitants. Specific heat-health vulnerabilities are often present in high-density urban neighbourhoods that lack open space and vegetation (Harlan et al., 2006; Stewart and Oke, 2012; Vanos, 2015). For example, Harlan et al. (2006) found that lower income and minority populations in Phoenix, AZ lived in warmer neighbourhoods that were crowded and had little greenspace. These residents were also exposed to corresponding health risks of high temperature exposure.

Elevated frequencies of total ambulance calls (Dolney and Sheridan, 2006) and, more specifically, of heat-related ambulance calls (Bassil et al., 2009) have been reported within certain areas of Toronto during hot weather. Recreational waterfront areas along Lake Ontario, large rail yards, low-income inner-city neighbourhoods, and areas with a high-density of homelessness report the highest incidences of heat-related morbidity in Toronto (Dolney and Sheridan, 2006; Bassil et al., 2009). In order to better understand the influence of distinct landscape characteristics on human health during EHEs, a more detailed characterization of high-risk urban landscapes and of specific landscape characteristics that influence human heat health is warranted. Accordingly, the goal of the proposed study is to examine, at the relatively fine spatial scale of the Census Tract (CT), the relationship between tree canopy coverage and heat-related morbidity during extreme heat events in Toronto, Canada.

2. Methods

2.1. Study area

The study area was the City of Toronto, Ontario, Canada (+43.7182°, −79.3774°; ~63,421 ha; ~2,615,000 population). The most recent national census (2011) divided Toronto into 544 CTs, which are defined as small areas with a relatively stable and socioeconomically homogeneous population between 2500 and 8000 (Statistics Canada, 2012a). Census Tracts were chosen as the areal unit for analysis since the relatively stable population between CTs limited the influence of changes in population on the results (e.g. heat-related ambulance calls). Finer-scale areal units (e.g. Dissemination Areas or Dissemination Blocks) were not used since greater numbers of these units within the City of Toronto (3685 Dissemination Areas and 12,896 Dissemination Blocks) would be more cumbersome for analysis, the population is not stable between Dissemination Blocks, and using the smaller units would have resulted in more units with no heat-related ambulance calls. Further, using CTs as the areal unit provided a relatively fine spatial scale for analysis as compared to previous studies that examined heat-related morbidity and mortality either across the single areal unit of the City of Toronto (Smoyer et al., 2000; Pengelly et al., 2007; Bassil et al., 2008, 2011; Vanos et al., 2012a) or within coarser-scale areal units (Bassil et al., 2009). Mean CT area was 116.6 ± 146.0 ha (range: 1.3–2023.3 ha).

Study Period Selection

Four EHEs were selected for the present study from the historical pool (2001–2011) of days officially classified as either Heat Alert (HA) and Extreme Heat Alert (EHA) days by Toronto Public Health (Toronto Public Health, 2012). HA/EHA are called in Toronto when a "hot air mass is forecast and the likelihood of deaths is more than 65/90 percent", respectively (Toronto Public Health, 2009a). Rather than basing event classification on meteorological factors alone (e.g. maximum daily air temperature (T_{max}) or indices such as the apparent temperature or Humidex), the HA/EHA approach uses the Spatial Synoptic Classification system, which focuses on human health and well-being (Sheridan and Kalkstein, 2004). The four EHEs that best satisfied the predetermined selection criteria (Table 1) were selected for the present study: 27–30 June, 2005; 29 July–2 August, 2006; 24–27 May, 2010; and 29 August–2 September, 2010 (n = 18 EHE days). Buffer periods of seven days before (Pre) and after (Post) each EHE were also examined. A total of five days (25 June, 2005; 26–27 July, 2006; 30–31 May, 2010) from the Pre and Post periods were classified as HA by Toronto Public Health (Toronto Public Health, 2012) and therefore removed from all analyses. The remaining Pre (n = 25) and Post (n = 26) days were used for this study. Heat-related morbidity was assessed based on the current day numbers (lag 0). Although heat-related mortality from all causes appears to peak with a one- to three-day lag following high temperatures (Semenza et al., 1996; Anderson and Bell,

Table 1
Selection criteria for EHEs (in order of decreasing importance).

Criterion	Reasoning for Criterion
1) Duration of event ≥4 consecutive HA/EHA days, excluding abnormally long events (e.g. a 9 d event in July, 2005)	Agrees with Environment Canada's duration criterion of a 'heat wave' as being "a period with more than three consecutive days at or above 32 °C" (Smoyer-Tomic et al., 2003; Health Canada, 2011); Agrees with previous reports that used 3–5 d events (Vanos et al., 2012a,b)
2) Ratio of weekdays:(weekend days + holidays) of ~4:1	Best representation of the proportion of day types in 'typical' heat events (Table 2); Accounts for differential weekday vs. weekend day/holiday effects on heat-related morbidity (Dolney and Sheridan, 2006)
3) Ratio of HA:EHA days of ~1:4	Best representation of the proportion of alert types in 'typical' heat events (Table 2)
4) Stand-alone events with no other HA/EHA days within 7 d pre- or post-event	Reduction of confounding effects of non-event HA/EHA days on results
5) Events from different times in the summer season	Accounts for any intra-seasonal variation of the thermal comfort-heat morbidity relationship, since acclimatization has been documented (Smoyer-Tomic et al., 2003; Sheridan and Kalkstein, 2004; Pengelly et al., 2007), especially in mid-latitude climates (Luber and McGeehin, 2008)
6) Events from more than one season	Accounts for any inter-seasonal variation of the thermal comfort-heat morbidity relationship
7) Most recent events take priority	Best representation of the present-day situation

EHEs, extreme heat events. HA/EHA, heat alert/extreme heat alert. 'Typical' heat events, see Table 2 for definition.

2009), the timing of the impact of heat on morbidity is less certain (Bridger et al., 1976; Kilbourne, 1997). One study in Phoenix, AZ found a lag of only three hours in heat-related morbidity (Golden et al., 2015), thus current day ambulance calls (a measure of morbidity) were used in this study.

2.2. Weather data

Open-source mean air temperature (T_a, °C) data were obtained for the dates of interest from two government-maintained airport weather stations in the Toronto area: Lester B. Pearson International A station (+43.6772°, −79.6306°; 173.4 m elevation) and Buttonville A station (+43.8622°, −79.3700°; 198.1 m elevation) (Environment Canada, 2012). Hourly data in Local Standard Time were converted to Daylight Savings Time (DST) by adding one hour. Daily mean data were obtained by averaging hourly values from the two stations. The lowest and highest mean hourly values per 24-h period defined the daily minimum air temperature (T_{min}, °C) and T_{max} (°C), respectively.

2.3. Heat-related ambulance call classification

Ambulance dispatch data (date, time (as DST), latitude/longitude coordinates of the call, and Medical Priority Dispatch System (MPDS) code) for the study dates were obtained from Toronto Emergency Medical Services under a data sharing and confidentiality agreement. The MPDS determinant code describes the problem and severity of the call (Olynyk, 2012). Ambulance calls categorized as the MPDS 'heat/cold exposure' code have been shown to be most strongly correlated to mean daily T_a in Toronto (Bassil et al., 2008), however these call classifications are rarely used and thus may not reflect the full impact of heat on morbidity (Bassil et al., 2009). Therefore, the present study defined heat-related ambulance calls using a broader subset of MPDS codes as previously described (Luber and McGeehin, 2008; Vanos et al., 2012a), including the following coded conditions: 06–Breathing Problems; 09–Cardiac or Respiratory Arrest/Death; 10–Chest Pain (Non-traumatic); 18–Headache; 20–Heat/Cold Exposure; 28–Stroke/Cerebrovascular Accident; and 31–Unconscious/Fainting. Daily total and heat-related ambulance calls were calculated for each 24-h period of interest.

2.4. Spatial distribution of ambulance calls

Coordinates of ambulance calls were projected onto the Toronto CT dataset (Statistics Canada, 2011) in a geographic information system (Environmental Systems Research Institute, Redlands, CA) to obtain the number of daily ambulance calls for each CT and for visualization of spatial distribution of calls. Ambulance call data were normalized to the population of each CT to account for any influence of varying populations on call data between different CTs.

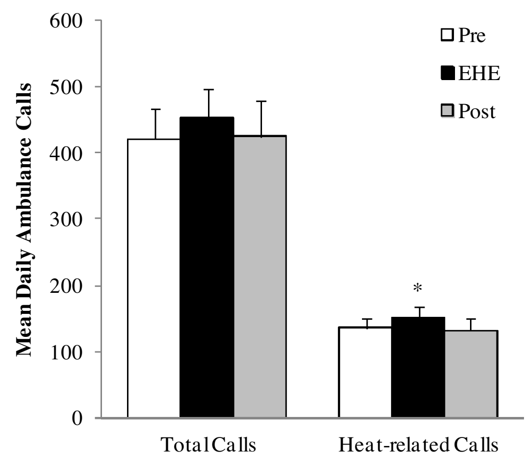

Fig. 1. Mean daily ambulance call frequency during Pre, EHE, and Post periods. Total calls include all heat- and non-heat-related calls. Data are mean ± SD. *Indicates statistical difference between EHE versus Pre and versus Post baseline periods within a call category. Pre/Post, baseline periods before/after EHEs. EHE(s), extreme heat event(s).

2.5. Canopy and hard surface cover analyses

The 'Tree Canopy' land class was extracted from the Toronto land cover raster dataset (City of Toronto – Parks, 2009) and proportional canopy cover of each CT was calculated. The 'Road' and 'Other Paved Surfaces' land classes were extracted from the Toronto land cover raster dataset and proportional hard surface cover of each CT was calculated. CTs were then ranked by either proportional canopy cover or proportional hard surface cover and organized into groups at 5% intervals for statistical analyses. To simplify visualization in Fig. 2, CTs were categorized into five classes using the Natural Breaks (Jenks) method. The resulting five classes were named: "Low" (0.0%–16.8% proportional canopy cover, n = 78 CTs), "Low-Medium" (16.8%–27.9% proportional canopy cover, n = 117 CTs), "Medium" (27.9%–37.7% proportional canopy cover, n = 155 CTs), "Medium-High" (37.7%–53.0% proportional canopy cover, n = 124

Table 2
Descriptive statistics for 'typical' and selected EHEs.

	Duration (d)	Weekdays (d)	Weekend days + Holidays (d)	HA days (d)	EHA days (d)
'Typical' EHEs	5.0 ± 1.5	3.8 ± 0.8	1.2 ± 0.9	1.3 ± 0.9	3.7 ± 1.9
Selected EHEs	4.5 ± 0.6	3.5 ± 0.6	1.0 ± 0.8	1.3 ± 0.5	3.3 ± 0.5

'Typical' EHEs determined by averaging data across all events of 4 d or longer from entire pool (2001–2011). Data are mean ± SD. All 'typical' vs. selected EHE comparisons were not significantly different. EHE(s), extreme heat event(s). HA/EHA, heat alert/extreme heat alert.

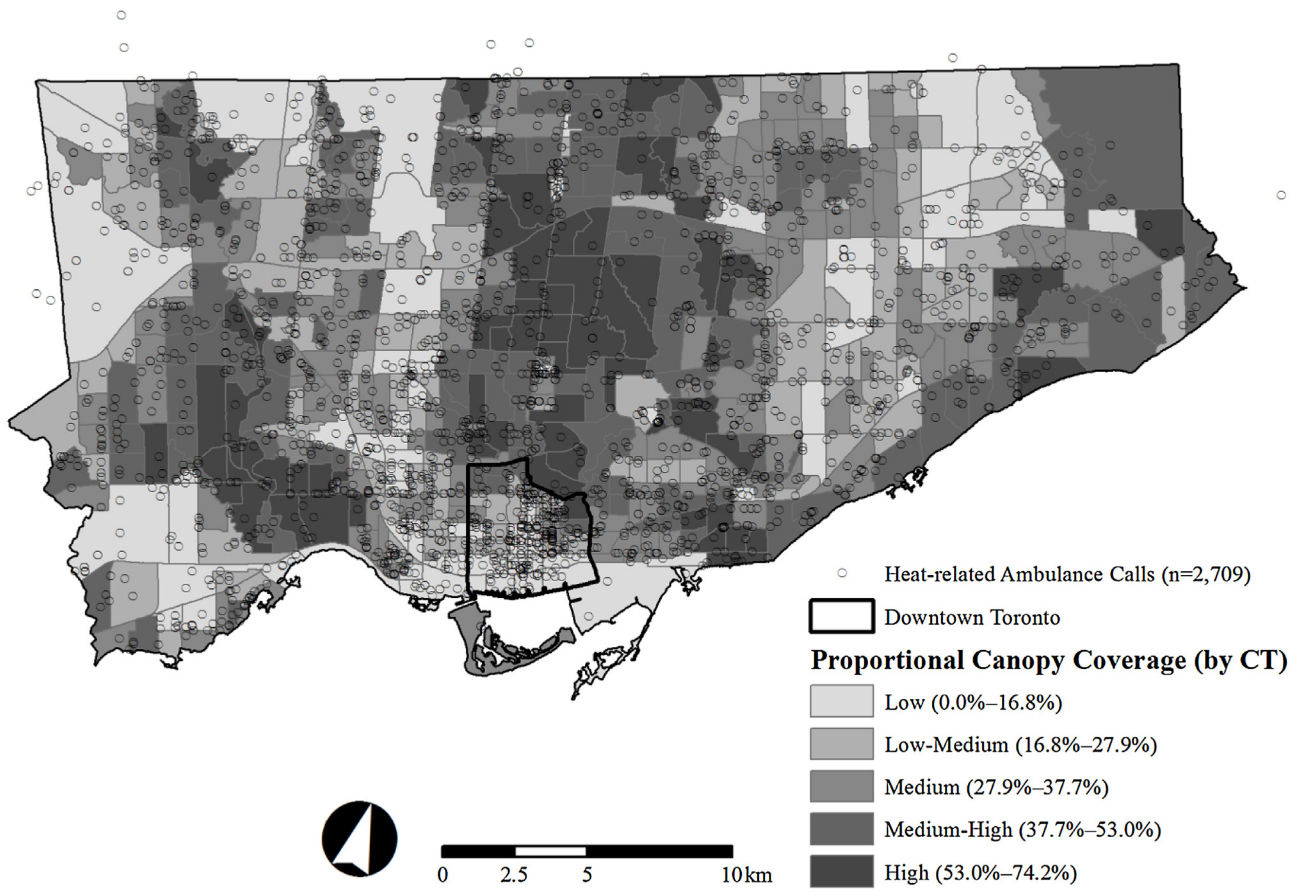

Fig. 2. The spatial distribution of heat-related ambulance calls (n = 2709) from all EHE study dates (n = 18) overlaid onto Toronto CTs (n = 544) categorized into five proportional canopy cover classes. Downtown Toronto is highlighted with a bold outline. CT(s), Census Tract(s).

Table 3
Daily air temperature data during each study period, averaged on an hour-by-hour basis between the Pearson and Buttonville weather stations.

	Pre	EHE	Post
T_a, °C	19.8 ± 3.0	25.6 ± 2.4*	20.4 ± 3.0
T_{min}, °C	14.2 ± 3.8	19.9 ± 3.2*	15.7 ± 2.8
T_{max}, °C	24.8 ± 4.0	31.2 ± 2.6*	24.7 ± 4.0

Data are mean ± SD. *Indicates statistical difference between EHE versus Pre and versus Post baseline periods within a measurement. T_a, mean air temperature. T_{min}, minimum air temperature. T_{max}, maximum air temperature. Pre/Post, baseline periods before/after EHEs. EHE(s), extreme heat event(s).

CTs), and "High" (53.0%–74.2% proportional canopy cover, n = 70 CTs).

2.6. Statistical analyses

Inter-group differences were examined by 1-way ANOVA with Tukey's post hoc comparison applied to significant main effects. The normality assumption was assessed using statistical (Shapiro-Wilk's test) and graphical (stem-and-leaf plot, frequency histogram, Q-Q plot, detrended Q-Q plot, box plot) interpretation methods. The CT-level ambulance call data failed normality testing. Spearman rank order correlations (a non-parametric test) were thus run for all correlation analyses involving CT-level call data. Assumptions of linearity, lack of outliers, and homoscedasticity were assessed graphically (scatter plots) and were reasonably met in all cases. A significance level of $p < 0.05$ was used. Analyses were performed using SPSS (v. 19.0.0, IBM Corporation, Armonk, NY).

3. Results

3.1. Study period characteristics

Selected EHEs satisfied all selection criteria (Table 1) with the exception of *"4 Stand-alone events with no other HA/EHA days within 7 d pre- or post-event"*. This criterion was only partially met due to the presence of five HA days from the Pre and Post periods, which were removed from all analyses as described in the Methods subsection 'Study Period Selection'. Descriptive statistics of the selected EHEs were not significantly different from typical values for the entire pool of available EHEs (Table 2). Daily air temperatures during EHEs were 5.6 °C, 5.0 °C, and 6.5 °C higher for T_a, T_{min}, and T_{max}, respectively, as compared to Pre and Post buffer periods (Table 3).

3.2. Ambulance call frequency

Total daily ambulance calls (i.e. heat- plus non-heat-related calls) were not significantly different between Pre, EHE, and Post periods (main period effect: $p = 0.095$) despite a 6.9% increase during EHEs (Fig. 1). Daily heat-related ambulance calls were significantly increased (+12.3%, $p = 0.005$) during EHEs as compared to Pre and Post periods, which were similar to each other.

3.3. Spatial distribution of ambulance calls

The spatial distribution of heat-related ambulance calls was similar to that of total calls. The greatest density of heat-related calls occurred in the south-central portion of the city, labelled Downtown Toronto in Fig. 2.

3.4. Spatial distribution of canopy coverage

CTs in Downtown Toronto have proportional canopy coverage values mostly in the Low (0.0%–16.8%) to Low-Medium (16.8%–27.9%) ranges (Fig. 2). By contrast, Downtown Toronto is flanked to the east and to the west by CTs with proportional canopy coverage values mostly in the Medium (proportional canopy cover: 27.9%–37.7%) and Medium-High (37.7%–53.0%) ranges. Similarly, CTs along the eastern waterfront have proportional canopy coverage values in the Medium to Medium-High range.

3.5. Census tract-level ambulance calls by proportional canopy cover

CT-level percentage canopy cover had a small-strength, negative correlation with heat-related ($\rho = -0.094$, $p = 0.029$) ambulance call frequency. A significant main effect of canopy cover (classified into 5% groups as described in the Methods) on heat-related ambulance call frequency was observed ($p < 0.0001$, Fig. 3A). The greatest reduction (80%) in heat-related ambulance call frequency appeared as the proportional canopy cover increased from <5% to >5%.

3.6. Census tract-level ambulance calls by proportional hard surface cover

A small-strength, positive correlation was found between CT-level percentage hard surface cover and heat-related ($\rho = 0.150$, $p < 0.001$) ambulance call frequency. The main effect of hard surface cover (classified into 5% groups as described in the Methods) on heat-related ambulance call frequency was significant ($p < 0.0001$, Fig. 3B). The greatest reduction (75%) in heat-related ambulance call frequency appeared as the proportional hard surface cover decreased from >75% to 70–75%.

4. Discussion

4.1. Temporal and spatial distribution of heat-related morbidity

The present observations of ambulance call frequency corroborate previous findings of increased heat-related morbidity (Semenza et al., 1999; Bassil et al., 2009,2011; Vanos et al., 2012a) during an EHE (Fig. 1). Further, the reported 10% increase in total ambulance call frequency in Toronto during HA/EHA days between 1999 and 2002 (Dolney and Sheridan, 2006) is similar to the present finding of a 7% increase. Greater relative elevations in heat-related ambulance call frequency have been reported in Toronto during heat events as compared to non-heat event periods (e.g. +29%)

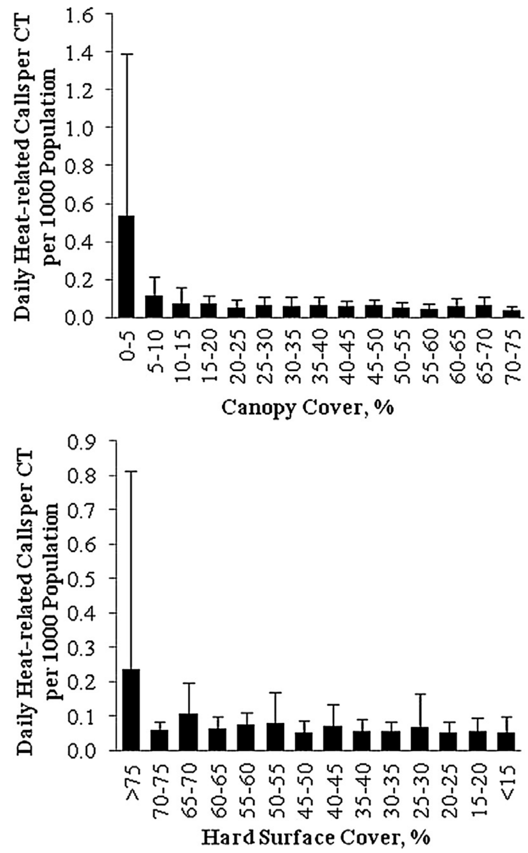

Fig. 3. Daily heat-related ambulance calls per CT (normalized to CT population) as a function of A) proportional canopy cover and B) proportional hard surface cover. Data are mean ± SD. Main effects are significant for canopy cover (ANOVA $p < 0.0001$) and for hard surface cover (ANOVA $p = 0.0002$). CT, Census Tract.

(Vanos et al., 2012a), however substantial annual differences in heat-related ambulance calls have been observed (e.g. ~3.5-fold between years) (Bassil et al., 2009). These findings contextualize the present observations of a ~12% increase in the frequency of heat-related ambulance calls during EHEs.

Spatial distribution of both heat-related (Fig. 2) and total ambulance calls during EHEs in the present study support previous findings of higher heat-related (Bassil et al., 2009; Vanos et al., 2012a) and total (Dolney and Sheridan, 2006) ambulance call densities near Toronto's urban core. An important factor to consider is that an ambulance dispatch location is not necessarily the same as the patient's place of residence or work (Toronto Public Health, 2009b) and transient populations, including foreign tourists and locals, are difficult to monitor. These can pose problems in cases where it would be desirable to normalize ambulance calls to a specific demographic. Detailed spatial analysis of calls was not a focus of the present study, however the consistency of this distribution pattern of ambulance calls is interesting and warrants future research.

The observed spatial distribution of calls in the present study also align with a "heat vulnerability index" for Toronto (Toronto Public Health, 2009b, 2011). This index assigns a vulnerability score to each CT in Toronto, based on the physical landscape (i.e. heat exposure) and a number of social, behavioural, medical, and physiological human factors (i.e. heat sensitivity) (Toronto Public Health, 2009b, 2011). One caveat of this vulnerability index is that it applies a static vulnerability score to specific areas of Toronto that are under the influence of dynamic phenomena (e.g. weather, transience of the population). It is nonetheless noteworthy that the resultant vulnerability maps from this index mimic the spatial distribution of total and heat-related ambulance calls during EHEs in the present study (i.e. highest density in the urban core and a relatively low density in the geographical centre of the city, previously described as a "doughnut" pattern) (Toronto Public Health, 2011).

4.2. Relationship between canopy cover and heat-related morbidity

Some generalized landscape typologies within Toronto, all of which would be considered to have a low amount of canopy cover and a high amount of hard surface cover, have been associated with increased heat-related morbidity and mortality. The urban core, urban streets, and untreed urban parks expose users to a greater proportion of incoming solar radiation (Vanos et al., 2012a), adding to the overall radiant load which is the most important parameter for determining human thermal comfort in warm conditions (Kántor and Unger, 2011; Johansson et al., 2014). Further, a strong negative relationship between the amount of solar radiation absorbed by a person and their thermal comfort has been reported (i.e. more radiation absorbed leads to reduced thermal comfort) (Vanos et al., 2012a). This finding suggests that reducing absorbed solar radiation by increasing canopy cover, in particular with densely-leaved tree species that minimize the transmission of solar radiation to ground level, will have a positive effect on human thermal comfort, and possibly heat health.

In addition to blocking the absorption of solar radiation, trees and other vegetation provide evaporative cooling to reduce the overall surface energy budget and thus cool local air and surface temperatures. Although the low sky view factor from buildings can result in radiative trapping at night and increase the nighttime UHI, the relatively cooler surfaces beneath trees result in less emitted long-wave radiation to be trapped and the evaporative cooling provided by the trees also decreases air temperature (Loughner et al., 2012). A modelling study in Washington, DC found that the additional tree shading and evapotranspiration provided by vegetation in an urban area decreased surface air temperatures in urban street canyons by 4.1 °C, road surface temperatures by 15.4 °C, and building wall temperatures 8.9 °C (Loughner et al., 2012). Coseo and Larsen (2014) also found that neighbourhoods with a higher percentage of impermeable surface cover, as compared to those with higher canopy cover, had higher nighttime surface temperatures. The two factors explained 68% of the temperature variance overnight between the two neighbourhoods, which increased to 91% during EHEs (Coseo and Larsen, 2014).

Additional urban landscape typologies, such as the urban core (Bassil et al., 2009), rail yards (Dolney and Sheridan, 2006), and recreational waterfront areas (Dolney and Sheridan, 2006; Bassil et al., 2009), have been associated with a higher incidence of heat-related morbidity and mortality. Toronto's high degree of urbanization has also been attributed to higher heat-related mortality (Smoyer et al., 2000). As mentioned above, the diurnal transience of population density in these areas (e.g. many people going to work downtown or to spend time along the recreational waterfront despite extreme hot weather) is important to consider. It is likely that a higher daytime population density in the downtown core or along the waterfront during EHEs contributed to elevated calls in these areas in the present study. This further supports the need to redesign these landscapes in a way that reduces peoples' risk of heat-related illness.

Collectively, these previous findings in the literature fit well with the present observations that heat-related morbidity is negatively correlated with proportional canopy cover and positively correlated proportional hard surface cover (i.e. asphalt and concrete not shaded by trees) at the CT level in Toronto (Fig. 3). Both observations suggest a role for the specific and modifiable landscape characteristic of tree canopy presence in abrogating the impact of extreme heat on human health. For example, the data presented in Fig. 3 suggest that increasing the proportional canopy cover in a CT from <5% to >5% could reduce heat-related ambulance calls in this CT by approximately 80%. Similarly, reducing the proportional hard surface cover in a CT from >75% to <75% could reduce heat-related ambulance calls in this CT by approximately 75%. There is inherent complexity in trying to tease out the specific (and opposite) influences of tree canopy and unshaded hard surface land cover on heat-related morbidity. While this was not the goal of the present study it presents as a valid research question worthy of further investigation. Nonetheless, the present observations and those previously published support the importance of planting large shade trees in urban areas (*and* supplying the necessary infrastructure to optimize tree health). This action is likely to have a positive impact on heat-related morbidity and will also help the City of Toronto work toward its goal of attaining a city-wide canopy cover of 40% by the year 2050 (Toronto Cancer Prevention Coalition, 2010). The present observations support the argument for increased urban canopy cover targets as landscape architects, urban planners, urban forest advocates, public health officials, politicians, and other professionals plan and design for urban-centric population growth and the changing global climate.

5. Conclusions

The present study observed elevations in extreme heat-related morbidity at the level of the CT in Toronto and corroborated previous findings. Furthermore, the occurrence of heat-related morbidity was more frequent in CTs with the lowest proportion of canopy cover and the highest proportion of hard surface cover. These observed relationships support the prioritization of planting shade trees and optimizing growing conditions as design strategies for improving human health in the urban environment. These findings could be utilized by designers, planners, and health officials to advocate for design modifications that aim for thermally neutral outdoor environments in areas in most need of improvement, in addition to reaping the many other benefits of increasing the urban tree canopy cover (e.g. habitat, gas exchange, softening of the urban landscape, aesthetically appealing). The present results advocate for the use of bioclimatic design principals in urban planning and the provision that effective green space should have a central position in resiliency planning and adaption to urban growth and climate change in large urban centres.

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