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Research article

The 2021 Western North American heat dome increased climate change anxiety among British Columbians: Results from a natural experiment

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ABSTRACT

Introduction: Extreme weather events caused by climate change pose a risk to mental health. Illustrating this reality, this study estimates the impact of the 2021 Western North American heat dome (June 25th, 2021 – July 1st, 2021) on climate change anxiety among British Columbians.
Methods: We conducted an online survey of British Columbians, aged ≥ 16. Participants were recruited using paid advertisements on social media. Data were collected pre- and post- heat dome between May 12th, 2021 – June 21st, 2021 (n = 439), and July 15th, 2021 – July 18th, 2021 (n = 420), respectively. A multivariable inverse Gaussian regression model tested differences in Climate Change Anxiety Scale (CCAS) scores pre- and post- heat dome. Potential confounders measured included age, gender, ethnicity, education, income, and political orientation. CCAS reliability was assessed using Cronbach's alpha.
Results: Most participants indicated that they were much (40.1%) or somewhat (18.4%) more worried about climate change due to the heat dome. Mean CCAS scores increased from 1.66 (standard deviation [SD]= 0.80) to 1.87 (SD = 0.87) pre- and post- heat dome, respectively. In multivariable modeling, this effect was significant after controlling for potential confounders (Estimate = 0.057, standard error = 0.148, $p < 0.001$). The CCAS reliability was high (Cronbach's alpha = 0.94).
Discussion: Our results found that British Columbians had significantly higher climate change anxiety following the 2021 Western North American heat dome. Ongoing monitoring of climate change anxiety is needed to understand the impact of individual and compounding climate change-related weather events over time.

1. Introduction

Climate change poses an urgent public health threat, in part due to its role in increasing the frequency, duration, and intensity of extreme weather events such as heat waves, floods, and droughts [1]. Scientists around the world have highlighted that high temperature extremes have worsened globally, and that average global temperatures are projected to rise at least 1.5 °C above pre-industrial levels by 2040, posing substantial risks to human health [2]. Extreme weather events caused by temperature changes, in addition to direct impacts on morbidity and mortality, can significantly disrupt interactions between socio-environmental factors and human health, leading to indirect health impacts due to consequent economic, food, housing, and job insecurity, or forced displacement [1]. Heat waves, described as temperatures above long-term averages where warm air masses are stagnant and high minimum temperatures occur successively over nights [3], can have multifaceted implications for public health, including elevated mortality [4], or exacerbation of pre-existing comorbidities such as cardio-respiratory conditions [5]. Therefore, exposure to high temperatures can increase emergency room visits, hospitalizations, or

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community-based healthcare demands, thus creating a significant burden on health systems [6].

While the impact of intense heat on physical health is well documented, the mental health repercussions from these events have received less attention, despite evidence showing that environmental hazards and the related mortality and morbidity from such hazards elevate the risk of certain mental health disorders [7,8]. Moreover, there is growing evidence that mental illness is one of the greatest health burdens worldwide [9]. Extreme weather events have been associated with an increase in various mental health problems such as anxiety, depression or post-traumatic stress disorder [10,11]. Anxiety, described as negative emotional state that causes physical symptoms and apprehension about the future [12], is seen as a particularly relevant psychological response to climate change, where it is referred to as climate change anxiety [13]. Heat waves specifically can cause stress that has been associated with mood and anxiety disorders [14] and elevated mortality in individuals with pre-existing mental illness [15].

The increase of climate-related mental health concerns has drawn attention to the lack of validated instruments that can be used to accurately assess and quantify this population health concern. However, recent efforts within this field have led to the development of a Climate Change Anxiety Scale (CCAS) by Clayton and Karazsia (2020) [16]. CCAS was developed in response to increasing concerns related to negative emotional responses to climate change. Considering their multifaceted impacts, it is reasonable to expect that extreme climate events may lead to certain levels of emotional distress (e.g., 'normal reactions to abnormal situations') [3]. Nonetheless, there is a risk of pathologizing such otherwise reasonable responses when conducting research assessing mental health in climate change contexts [13]. In contrast, as climate change risks increase, worries about the effects of climate change may lead to elevated levels of anxiety causing cognitive, emotional and functional impairment [13,16]. As such, it is important to differentiate between 'adequate' emotional responses and 'extreme' psychosocial reactions in this context [16]. By integrating such considerations, the CCAS is an innovative tool aiming to identify significant levels of climate change anxiety. Additionally, CCAS is a validated tool that can be used to track population-level changes to climate change anxiety and enhance efforts advocating for mental health support and services during and following climate disasters.

The CCAS is a 22-item scale that measures emotional responses to climate change among adults and includes correlated sub-scales assessing cognitive and emotional impairment, functional impairment, and behavioural engagement related to climate change events.

The unprecedented heat wave that took place in Western North America further demonstrates the implications of these concerns. Between June 25th and July 1st, 2021, most regions in the Pacific Northwest experienced record-breaking temperatures reaching up to 49.6 °C [17]. The intense and long-lasting heat contributed to the formation of a heat dome, described as large areas of scorching heat being trapped in the atmosphere [18]. In British Columbia (BC) alone, almost 750 excess deaths were considered directly attributable to the heat dome [19]. The event marked the hottest June on record in Western North America, highlighting crucial gaps in the current health system and climate adaptation strategies, especially in the realm of mental health concerns. Most significantly, at present, there are no known indicators describing potential climate change impacts on mental health in Canada. Our study aims to address this gap and assess the effect of the 2021 heat dome on climate change anxiety levels among British Columbians using the CCAS scale.

2. Methods

2.1. Study design and data collection

We conducted a quasi-experimental study analyzing the impact of the 2021 heat dome in relation to changes in CCAS scores among adults in BC. Data were collected as part of a serial cross-sectional online survey with independent samples using the Survey Monkey platform [20]. Participants were recruited using paid advertisements on Facebook and Instagram and incentivised to respond using a prize draw for a $200 CAD VISA Gift Card. We used a targeted sampling strategy, with advertisements being targeted to individuals aged ≥16 years living in BC. A total of $6147.87 CAD was spent on advertisements, resulting in 880,047 impressions among 408,982 people. These impressions resulted in 11,735 clicks from 9916 people. The average cost per click was $0.52 CAD.

We determined the sample size for this study by performing power analyses informed by Clayton and Karazsia (2020) [16], who originally tested the distribution of CCAS scores using a sample of 297 respondents recruited in the US using Amazon's Mechanical Turk platform. In their analyses of these responses, cognitive impairment subscale scores had a mean score of 1.75 with a standard deviation (SD) of 0.97 and functional impairment subscale scores had a mean score of 2.09 and an SD of 1.08.

This study was powered to detect a mean difference of 0.20 on functional impairment subscale scores, as it had the larger SD of the two CCAS subscales. Setting alpha at 0.05 and power at 0.80, our power analyses indicated a required sample size of 458 responses per wave. We assumed a missing data rate of 37%, 10% greater than Clayton and Karazsia's, since we assumed our online sampling method would recruit less experienced survey takers than Amazon's Mechanical Turk platform. As such, our target recruitment rate was 726 participants for each wave of the survey.

The first wave of data collection for our first sample (n = 439) was conducted prior to the heat dome (May 12th, 2021- June 21st, 2021) as part of a research initiative aiming to descriptively explore the current levels and patterns of climate change anxiety among the general adult population in BC. The second wave of data collection (n = 420) for a distinct second sample was conducted between July 15th, 2021, and July 18th, 2021. The decision to pursue a second wave of data collection was influenced by the occurrence of the heat dome and the opportunity provided by this event to conduct more nuanced analyses and was not initially anticipated. Recruitment took longer for the first wave due to advertising spending limits imposed by Facebook on new accounts. As the spending limits were gradually increased, wave 2 of the survey was completed faster.

2.2. Variables of interest

The variables of interest for our bivariable analysis were survey items related to changes in climate related concerns pre- and post-heat dome. Such items included participants' evaluation of whether they were impacted by the heat dome (not impacted at all, impacted only a little, somewhat impacted, impacted to a great extent), participants' level of worry about climate change after the heat dome (much less worried, somewhat less worried, worry not changed, somewhat more worried, much more worried), whether participants were concerned about climate change impacting the industry they are working in (no, yes), or participants' perception of potential risks that the area where they live will be devastated by climate change (don't know/unsure, somewhat likely, somewhat unlikely, very unlikely).

The outcome variable for our multivariable analysis was the measure of climate change anxiety among British Columbians as determined by the calculated CCAS scores, including the functional subscale, cognitive subscale, behavioural subscale, and overall CCAS scores, pre- and post- the 2021 heat dome. Of the total 22 items included in the scale, indicators 1−13 measure the overall climate change anxiety scale, as follows: (1) Items 1−8 assess cognitive-emotional impairment (i.e., CCAS Cognitive Subscale) with questions such as "I find myself crying because of climate change"; and (2) Items 9−13 measure functional impairment (i.e., CCAS Functional Subscale)

with indicators like "My concerns about climate change undermine my ability to work on my potential". In addition, items 17–22 separately measure behavioural engagement in climate-related events (i.e., CCAS Behavioural Engagement Subscale) with questions such as "I feel guilty if I waste energy") [16].

The exposure variable was whether observations were made prior to or after the heat dome (i.e., wave 1 and wave 2 of data collection, respectively).

We selected potential confounders based on empirical knowledge of factors that are likely associated with climate change anxiety and climate-related extreme weather events such as heat waves. Potential confounders included in the multivariable inverse Gaussian regression analysis included age (<24, 25–44, 45–64, 65+ years), gender (man, woman, non-binary), ethnicity (white, Indigenous, Chinese, South Asian, other), education (bachelor's degree, graduate training, advanced training below bachelors, high school diploma, or less), income (ten level variable starting from $10,000 to $19,999 to $100,000 and over), and political orientation (extremely liberal, moderately liberal, slightly liberal, neither liberal nor conservative, slightly conservative, moderately conservative, and extremely conservative).

2.3. Data analysis

All statistical analyses were completed in R (version 4.0.3) [21]. Observations with missing data on our selected outcome or explanatory factor were excluded and a complete case analysis was performed. Descriptive statistics were calculated and stratified by wave of data collection. Chi-square tests assessed bivariable differences between wave 1 and wave 2 CCAS scores. A multivariable inverse Gaussian regression model tested differences in CCAS scores, with the wave of data collection as the primary explanatory variable, adjusting for age, gender, ethnicity, education, income, and political orientation. We used inverse Gaussian modeling due to the observation that the outcome variable (i.e., CCAS scores) was right skewed and the linear regression models were heteroskedastic. In sensitivity analyses, we built multivariable models with Poisson and Linear regression – finding that the overall conclusions of our paper were not sensitive to model building approach beyond the magnitude of the effect size (Range: β = 0.05 using inverse Gaussian [$p < 0.001$], 0.10 using Poisson regression [$p < 0.001$], and 0.18 using Linear regression [$p < 0.048$]). Model fit was tested using standard visual diagnostic plots.

2.4. Ethics

Ethics approval for this study, including the use of the survey for research and an amendment to use the survey for a second wave of data collection, was received from the Research Ethics Board (REB) at Simon Fraser University (SFU) (REB#: 30000309). The amendment included minor modifications to the survey and received ethical approval by SFU REB prior to the start of the second wave of data collection.

3. Results

The survey was initiated by 1551 participants (N_1 = 741, N_2 = 810). We excluded 16 participants who did not agree to the consent form terms and 7 participants who did not live in BC. Among wave 2 participants, 9 had taken the survey during wave 1 and 36 were unsure if they had taken a survey. These individuals were excluded to ensure independence of observations. This resulted in a final sample size of 1438. For these analyses, we conducted a complete case analysis by omitting participants with missing data across any of the variables included in our final multivariable model. This resulted in a final analytic sample size of 859 (N_1 = 439, N_2 = 420).

Table 1
Socio-demographic characteristics for individuals included in the pre- and post-2021 heat dome data collection stages (N = 859).

	Pre-heat dome N (%)	Post- heat dome N (%)	p-value*
Age			
≤24	69 (15.7)	57 (13.6)	0.559
25–44	175 (39.9)	158 (37.6)	
45–64	129 (29.4)	131 (31.2)	
65+	66 (15.0)	74 (17.6)	
Gender			
Man	215 (49.0)	217 (51.7)	0.133
Woman	201 (45.8)	192 (45.7)	
Non-binary	23 (5.2)	11 (2.6)	
Ethnicity			
White	361 (82.2)	374 (89.0)	**0.007**
Indigenous	24 (5.5)	17 (4.0)	
Chinese	18 (4.1)	7 (1.7)	
South Asian	15 (3.4)	3 (0.7)	
Other	21 (4.8)	19 (4.5)	
Education			
Bachelor's degree	139 (31.7)	107 (25.5)	0.098
Graduate Training	79 (18.0)	89 (21.2)	
High school diploma or less	69 (15.7)	84 (20.0)	
Advanced Training, below Bachelors	152 (34.6)	140 (33.3)	
Income			
<$10,000	76 (17.9)	82 (18.6)	0.078
$10,000 to $19,999	55 (12.5)	34 (8.1)	
$20,000 to $29,999	54 (12.3)	46 (11.0)	
$30,000 to $39,999	41 (9.3)	33 (7.9)	
$40,000 to $49,999	31 (7.1)	36 (8.6)	
$50,000 to $59,999	41 (9.3)	38 (9.0)	
$60,000 to $69,999	30 (6.8)	28 (6.7)	
$70,000 to $79,999	28 (6.4)	20 (4.8)	
$80,000 to $89,999	21 (4.8)	19 (4.5)	
$90,000 to $99,999	15 (3.4)	22 (5.2)	
$100,000 and over	58 (13.2)	47 (11.2)	
Political Orientation			
Extremely liberal	99 (22.7)	117 (28.0)	0.058
Moderately liberal	100 (22.9)	118 (28.2)	
Slightly liberal	24 (5.5)	21 (5.0)	
Neither liberal nor conservative	85 (19.5)	75 (17.9)	
Slightly conservative	31 (7.1)	19 (4.5)	
Moderately conservative	70 (16.0)	52 (12.4)	
Extremely conservative	28 (6.4)	16 (3.8)	

* p-values calculated using chi-square and fisher exact.

Table 1 shows the socio-demographic characteristics of our population sample. The sample included approximately equal numbers of men and women in the pre- and post- heat dome samples (men: N [%]: 215 [49%] vs 217 [51.7%], women: N [%]: 201 [45.8%] vs 192 [45.7%], pre- and post- heat dome, respectively), and a small number of non-binary individuals (N [%]: 23 (5.2%) vs 11 [2.6%]). Most participants were white (82% vs 89% pre- and post- heat dome, respectively), and in the 25–64-year-old age category (69.3% vs 68.8%).

Table 2 highlights the changes in climate related concerns pre- and post- heat dome. Overall, there was a significant increase in the participants' overall CCAS score pre-and post- heat dome (mean [SD], 1.66 [0.80] vs 1.87 [0.87], $p < 0.001$), as well as in their CCAS Cognitive Subscale scores (mean [SD]: 1.65 [0.80] vs 1.84 [0.86], $p = 0.001$), and CCAS Functional Subscale Scores (mean [SD]: 1.68 [0.87] vs 1.92 [0.98], $p < 0.001$). There was no significant increase in the scores for the CCAS Behaviour Engagement Subscale (mean [SD]: 3.59 [0.83] vs 3.60 [0.85], $p = 0.931$). CCAS reliability was high for the overall CCAS scale, as well as the CCAS Cognitive and CCAS Functional Subscales (Cronbach's alphas = 0.94, 0.92 and 0.89, respectively).

Additionally, there was a significant increase in participants' concern that the industry they are working in will be affected by climate change ($p < 0.05$), and that the area where they live will be devastated by climate change events such as floods or forest fires

Table 2
Changes in Climate Related Concerns for individuals included in the pre- and post- the 2021 heat dome data collection stages (N = 859).

	Pre-heat dome N (%)	Post- heat dome N (%)	p-value*
Have you ever been displaced due to a natural disaster or severe changes in your environment? (e.g., floods, forest fires, drought, loss of agriculture)			
No	407 (92.7)	380 (91.1)	0.468
Yes	32 (7.3)	37 (8.9)	
How likely or unlikely do you think the industry you're working in will be affected by climate change?			
Very unlikely	115 (26.8)	87 (21.3)	**0.024**
Somewhat unlikely	66 (15.4)	43 (10.5)	
Unsure	35 (8.2)	33 (8.1)	
Somewhat likely	63 (14.7)	81 (19.8)	
Very likely	150 (35.0)	165 (40.3)	
Thinking of where you currently live, how likely or unlikely is it that your region will be devastated due to climate related changes? (e.g., floods, forest fires, drought, loss of agriculture)			
Don't know or unsure	15 (3.4)	11 (2.6)	**<0.001**
Somewhat likely	131 (29.8)	148 (35.3)	
Somewhat unlikely	77 (17.5)	69 (16.5)	
Very unlikely	139 (31.7)	66 (15.8)	
Very likely	77 (17.5)	125 (29.8)	
In early July, British Columbia experienced a record-breaking heat wave referred to in the media as the "heat dome." Subsequent fires across the province led to fires in Lytton, British Columbia and other regions. To what extent were you impacted by the heat wave in early-July?			
I was not impacted at all	–	56 (13.4)	–
I was impacted only a little	–	119 (28.4)	
I was somewhat impacted	–	171 (40.8)	
I was impacted to a great extent	–	73 (17.4)	
As a result of the heat dome and subsequent fires across the province, are you more or less worried about climate change?			
I am much less worried about climate change	–	17 (4.1)	–
I am somewhat less worried about climate	–	12 (2.9)	
My worry about climate change has not changed	–	145 (34.6)	
I am somewhat more worried about climate change	–	77 (18.4)	
I am much more worried about climate change	–	168 (40.1)	
Climate Change Anxiety Scores			
Overall CCAS Scores *(Mean [SD])*	1.66 (0.80)	1.87 (0.87)	**<0.001**
CCAS Cognitive Subscale Scores *(Mean [SD])*	1.65 (0.80)	1.84 (0.86)	**0.001**
CCAS Functional Subscale Scores *(Mean [SD])*	1.68 (0.87)	1.92 (0.98)	**<0.001**
CCAS Behavioural Engagement Subscale Scores *(Mean [SD])*	3.59 (0.83)	3.60 (0.85)	0.931

Abbreviations: CCAS- Climate Change Anxiety Scale; SD- standard deviation.
* p-values calculated using chi-square and fisher exact.

Table 3
Multivariable analysis results showing changes in CCAS scores pre- and post- heat dome (primary analysis).

	β*	SE	T	P
Before or After Heatwave *(Ref* = Before Heat dome*)*				
After heat dome	**0.057**	**0.148**	**3.826**	**<0.001**

* Estimate. *Potential Confounders included in the inverse Gaussian regression model:* age, gender, ethnicity, education, income, and political orientation.

($p < 0.001$). Most participants reported that they were somewhat (40.8%) as well as greatly (17.4%) impacted by the heat dome. Similarly, most participants reported that they were much (40.1%) or somewhat more (18.4%) worried about climate change after the heat event.

Table 3 outlines the inverse Gaussian multivariable model results, which suggest that the mental health impact of the heat dome, measured by changes in CCAS scores pre- and post- heat dome, was statistically significant after controlling for potential confounders (Estimate = 0.057, standard error = 0.148, $p < 0.001$).

4. Discussion

The current study found that the 2021 Western North American heat dome was associated with a significant increase in climate change anxiety and climate-related concerns among British Columbians.

To our knowledge, this study is the first to use a natural experiment design to describe the impact of climate-induced extreme heat on mental health and anxiety levels among the general public in BC. Our study is also the first to use a validated climate change anxiety measurement tool to explore impacts of extreme heat on mental health, therefore providing uniquely novel insights that can forward emerging research in this field. Other studies exploring the effect of heat on population health in Canada primarily focus on mortality or physical health outcomes. For example, one study showed that older individuals aged 45 to 64 years experienced increased odds of mortality during the 2009 heat wave in Vancouver [22]. Globally, our study results are largely consistent with other research exploring climate-related mental health impacts. A recent systematic literature review identified 35 studies that suggest significant associations between heat and various mental health outcomes [23]. Notably, there is growing literature describing concepts of ecological anxiety, which are used to highlight the increasing prevalence of distress and worries about climate change and its effects [24]. Nonetheless, this research field remains largely underexplored in Canada. Our findings highlight the immediate reality of heat-dome-related anxiety as a significant public health concern in BC and emphasize the need for additional studies that can inform climate change adaptation strategies that incorporate mental health considerations. Our results can be used to complement other national or global studies and inform larger, more comprehensive research efforts, such as developing mental health monitoring systems to inform relevant decision making and policy development. Including mental health indicators in health policy efforts is crucial to avoid potential socioeconomic losses caused by climate change-related mental health challenges.

4.1. Strengths and limitations

The most significant strength of our study was the timeline of the data collection as part of our study design (i.e., pre- and post- heat

dome). The first wave of data collection ended four days prior to the start of the heat dome, and the wave 2 data collection commenced only two weeks after the heat dome ended. This provided an opportunity to collect real-life and real-time data at two relevant time points that are highly relevant to the environmental phenomenon of interest (i.e., heat dome), therefore adding to the limited evidence examining heat-related health outcomes in a quasi-experimental setting [25]. While the serial cross-sectional methodology allowed us to evaluate climate change anxiety levels immediately before and after the heat dome, our results can inform studies exploring long-term effects of climate-related extreme weather events on mental health. Other significant strengths include the significant statistical power of our study, and the novel use of a validated climate anxiety scale to generate climate-related insights relevant to BC. While the CCAS scale was validated in a US setting, our study provides validity evidence for the use of the CCAS in a Canadian setting.

The opportune timing of our data collection increases the ecological validity of the study, while reducing recall bias. Nonetheless, as with most self-reported data, there is a possibility that some participants' answers might not accurately reflect their behavior or situation, therefore increasing response bias. This is particularly relevant in the context of our survey due to its focus on mental health and climate change, which raises the potential for subjective measurements of wellbeing [26], as well as the risk of social desirability bias, previously highlighted as a potential concern in environmental psychology research [27]. Additionally, the survey was randomly advertised and distributed on social media channels—and was not a paid by survey platform where the population completing the surveys differs from the general population. The use of social media for data collection was a cost-effective opportunity to reach an adequate sample size, which is consistent with literature highlighting the advantages of recruiting study participants via social media [28]. Notably, given that we only addressed the occurrence of the 2021 heat wave in BC, our results have reduced external validity and should be interpreted with caution in wider settings. Moreover, while the random selection of participants reduced the risk for sampling bias in our study, our survey was only completed by individuals with access to social media. Additionally, even though our advertisements included photographs of ethnically diverse individuals, the survey largely failed to attract participants from diverse backgrounds, and our two samples included predominantly white individuals. This limits generalizability of the findings. Having a predominantly white sample also did not allow for an intersectional examination of the data. While our outcome measures a comprehensive range of elements related to climate change anxiety, future research should explore how climate-related events may differentially impact populations at risk of being disproportionally affected by climate change anxiety, such as Indigenous communities [29,30]. As such, integrating considerations relevant to social determinants of health is needed to inform inclusive and equitable public health responses. In addition, our study can be used to inform more diversity-focused surveys and frames of reference for climate change impacts based on social and structural determinants of health, and emphasizes the need for further disaggregated data and analysis to forward this field.

4.2. Conclusion

The impacts of climate-related extreme weather events such as heat waves are likely to continue to intensify in the following decade. Our study results highlight that British Columbians were negatively impacted by the 2021 Western North American heat dome (June 25th, 2021 – July 1st, 2021), which was associated with increased climate change anxiety in this region. This draws attention to climate change anxiety as an emerging and pressing public health concern across the province. As such, our findings indicate a compelling urgency to incorporate mental health indicators into future decision-making policies. Our results also indicate a strong need for capacity building aiming to increase psychosocial resilience as a crucial component of climate adaptation and mitigation strategies. While our study provides valuable insights into the potential threats posed by climate change-related extreme weather events, further research is urgently needed to explore potential monitoring, surveillance, and interventional solutions focused on addressing climate change anxiety across Canada.

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Author agreement

All the authors declare that they have seen and approved the final version of the manuscript being submitted.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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