Overview

Heat, health, and humidity in Australia's monsoon tropics: a critical review of the problematization of 'heat' in a changing climate

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Exposure to heat has killed more people in Australia than all other natural hazards combined. As the climate warms, temperatures are projected to rise substantially, increasing the impact of heat stress and heat illness nation-wide. The relation between heat and health is profoundly complex, however, and is understood differently across multiple sectors. This paper thus provides a critical review of how heat is currently measured and managed in Australia, highlighting how humidity, exposure, and exertion are key elements that are not consistently incorporated into 'problematizations' of heat. The presence or absence of these elements produces different spatial and temporal geographies of danger, as well as different governance practices. In particular, the invisibility of humidity as having a significant impact on heat and health shapes whether Australia's tropical monsoon zone is visible as a region at risk or not, and whether prolonged periods of seasonal heat are treated as dangerous. Similarly, different populations and practices become visible depending on whether the human body (its exposure, exertion, cooling, and hydration) is included in accounts of what constitutes 'heat.' As a result, the outdoor, manual workforce is visible as a population at risk in some accounts but not others. A brief review of key policy areas including housing, public health and work health and safety is presented to demonstrate how specific problematizations of heat are critical to the identification of, and response to, current and future climatic conditions. This has implications for how populations, places, and practices are constituted in the region.

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INTRODUCTION

Australia is well known for its extreme conditions. Bushfires, cyclones, droughts, and floods are familiar scenarios in the story of life on a harsh continent. Yet, exposure to heat kills more people nationally than all other natural hazards combined.[1,2] Despite its significance, extreme heat remains relatively difficult to identify, communicate, and govern. Not a visible or audible event, extreme heat has earned the moniker 'the silent killer.'[3] Its impacts as heat stress, heat illness, heat exhaustion, and heat stroke can also be difficult to identify. Heat exposure may elicit symptoms associated with cardiovascular and respiratory illness and it is often coded as such in public health data.[4] Nonetheless, harm resulting from extreme heat can be discerned through epidemiological studies of morbidity and mortality including hospital presentations and ambulance call outs that correspond with heatwave events.[4,5] The relationship between heat and health in Australia has predominantly been determined through mortality and morbidity analyses of heatwaves in southern regions, with consensus that infants, the elderly, and those with chronic medical conditions are the most vulnerable to heatwave-related illness or death (e.g., see Refs 6–10).

Heat in Australia is also understood to have a wide range of impacts on wellbeing and the ability to work safely and effectively. Exposure to extreme heat exacerbates pre-existing mental health conditions,[11] negatively affects mood and wellbeing, and increases levels of violence and suicide rates.[12,13] There is also a positive association between higher ambient temperature and occupational injury,[14] and extreme heat in Australia is also understood to detract from quality of life and reduce productivity at work by an average of A$6.9 billion every year.[15] As current and projected climate change causes temperature rises across Australia,[16,17] the 'heat health burden' is also likely to increase significantly nation-wide.[18–20]

This range of impacts indicates that heat and its relationship to health are understood in multiple ways. These constructs come with very different social, material, and political implications for the governance of everyday life and adaptation to climate change. This paper thus reviews the multiple ways in which heat is currently measured and managed in Australia. It then identifies how differences between these 'problematizations' of heat affect the extent to which Australia's tropical monsoon zone is depicted as being at risk. There is limited literature on heat and its impacts on health available for this region. Therefore, rather than attempting a systematic review or scoping study[21] we have opted for a critical review[22,23] of both the academic and policy literatures, focusing on those related to the region or its characteristics.

The paper begins by explaining the methodological approach. It introduces Foucault's concept of 'problematization' and its relationship to governance practices. Part 1 then examines how heat is problematized in terms of the inclusion or exclusion of different environmental variables, and the implications this has for how we understand the geography of extreme heat in Australia. The paper then considers how understanding heat in terms of its effect on the human body shifts the functional account of 'heat' to include physical exposure and exertion, which in turn generates alternative geographies of heat and its governance in terms of the populations and practices likely to produce this form of heat. Part 2 then considers Australia's monsoon tropics in more detail, examining how policies aimed at managing heat govern the places, populations, and practices that are rendered visible or invisible in these different accounts of heat. It particularly notes the (in)visibility of outdoor and labor-intensive work in the region as a location for, and target of, governance and adaptation strategies responding to contemporary and projected extreme heat. Collectively, these perspectives offer a critical appreciation of heat stress and its governance in tropical Australia, but with a wider relevance to the global tropical monsoon zone and the issue of climatic variations within jurisdictions, and variations over time and between populations.

Methods: The Significance of Problematizations for the Governance of Climate Change

This paper provides a cross-disciplinary critical review of heat and its relation to health in Australia, with a focus on the tropical monsoon zone. For conceptual coherence and critical traction, we utilize the Foucaultian concept of *problematization*. This concept arises within poststructural political theory in which knowledge, meaning, strategy, and policy are understood to be historically contingent, necessarily shaped by relations of power and influenced by ontology, epistemology, and the types of technologies available for use.[24,25] This helps us to identify multiple understandings of heat within policy and disciplinary discourses in Australia. These different problematizations produce different 'objects' of knowledge.[26,27] The ontological and epistemological assumptions of each account makes certain subjects and objects visible and others invisible, including

physical elements and processes as well as values and identities. The particular constellation of meaning each problematization establishes produces in turn particular fields of intervention and certain rationales or objectives that justify particular kinds of intervention.[28] In this way, each problematization helps produce a particular form of governance, or *governmentality*. A governmentality deploys practices and techniques appropriate to the account of the problem and the desired outcomes it is associated with, usually understood at the broadest level as ideal subjectivities, populations, or ways of life.[29]

Different problematizations render visible different targets of governance, and generate particular strategies and tactics for achieving their desired ends. In doing so, they produce particular geographies—or places, populations, and practices—to whom heat matters, or which matter for heat. This critical review develops these ideas in two stages. *Humid* heat as a distinct problematization emerges from Part 1 of the review. In order to explore how humidity's (in)visibility might play out in broader understandings of why heat is understood to matter for health, Part 2 reviews extant policies pertaining to heat in the jurisdictions that fall across the 'hot and humid' region. Of necessity, the breadth of this review means the detail in any one area will be limited. However, in highlighting disjunctures between different accounts of heat and its governance, we hope to bring attention to significant areas of exclusion, confusion, and tension in how adaptation to extreme heat is currently being governed in Australia's tropical monsoon zone, in relation to current and future conditions.

A Note on Naming Climatic Regions in Australia's North

In order to discuss the (in)visibility of Australia's hot and humid north there is a need to name the region. The naming of the elements that comprise a problematization is inherently political in terms of what is made visible and thereby valued, or not. We have tried to draw on, and be sensitive to the meanings of, existing discourses in doing so. The Köppen–Geiger climate classification[30] of global climatic zones places the region discussed here within the 'Tropical Monsoon' zone. This relates closely to the 'Northern Australia' super cluster of Natural Resource Management (NRM) regions, which form the geographical parameters of the most recent set of national climate projections. The northern Australia super cluster is made up of the 'Monsoonal North' and the 'Wet Tropics' clusters.[16] However, 'Northern Australia' also refers to a zone of economic and political development, which comprises the entire area north of the tropic of Capricorn, approximately half of the Australian landmass,[31] including arid and sub-tropical areas as well as the monsoon tropics. To avoid confusion with this larger area, and the differences of climate that it obscures, in this paper we refer to the hot and humid region as the *tropical monsoon zone*, or *monsoon tropics* for brevity.

The monsoon tropics spans the northernmost regions of three state/territory jurisdictions: Western Australia, the Northern Territory, and Queensland. Figure 1 (below) of Australian climate zones represents these jurisdictions and the approximate reach of the monsoon tropics, which it labels as the 'Hot Humid Summer' region. There is significant variation within this region. Northern Queensland contains more typically 'tropical' climates and higher elevations with lower temperatures. The 'top end' of the Northern Territory has a quite starkly defined wet and dry season, and the northern parts of Western Australia have far higher ambient temperatures than the other jurisdictions. The approximate geographic correspondence of the tropical monsoon zone with the northern Australia super cluster means that its climate projections information is relevant to the region.

PART 1: PROBLEMATIZING HEAT

Shifts in the Problematization of Heat as Ambient Temperature

There are a number of ways of problematizing heat. Each entails contestation over what variables should be included, how they should be calculated, and how the results of such calculations should be communicated and utilized.[33] The most common characterization of heat in relation to environmental conditions is as ambient temperature. Temperature is reported daily or more frequently, with maximums and minimums regularly populating the screens and airwaves in weather reports. As such, heat is often assumed to be most dangerous when ambient temperatures are highest. Maps demonstrating daily temperature extremes, such as the one below (Figure 2, Ref. 34), are often assumed to identify the spatial distribution of dangerous heat. In Australia, the highest ambient temperatures (40°C and above) are more likely to be reached in the central and southerly part of the continent. Daily reporting of temperature extremes thus produces a national imaginary of the most dramatic and dangerous heat being located in these regions,

FIGURE 1 | Australian climate zones based on temperature and humidity.[32] Reproduced by permission of Bureau of Meteorology, © 2017 Commonwealth of Australia.

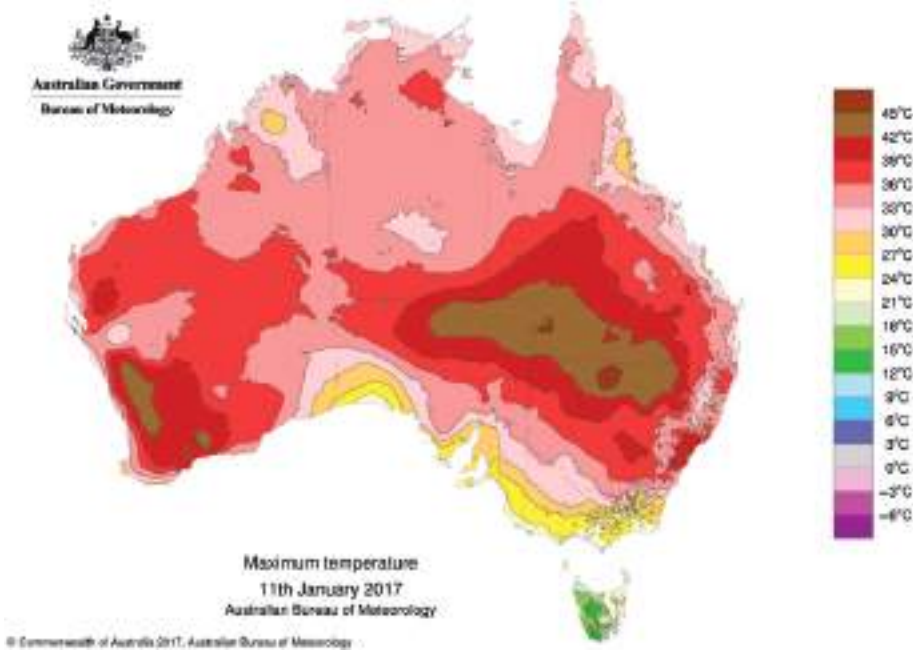

FIGURE 2 | Example of daily ambient temperature mapping. This map shows maximum temperature (°C) recorded on January 11, 2017.[34] Reproduced by permission of Bureau of Meteorology, © 2017 Commonwealth of Australia.

although meteorologically this is not how extreme weather is typically discussed. For example, if these temperatures were averaged over longer periods of time, the north would tend to have a higher average daily maximum temperature even without reaching such extremes.

Prior to 2014, there was no national definition of what constituted dangerous heat or a heatwave. Operational temperature criteria for heat health warnings varied by city and region. In some cases, heatwaves were defined as periods where multiple consecutive days exceeded locally defined maximum

temperature thresholds. For example, the city of Adelaide defined a heatwave as 5 days of 35°C or above, or 3 days of 40°C or above.[35]

Understanding extreme heat in terms of ambient temperature thresholds has also been adopted by climate change projections and impact assessments. Australian climate change projections publications typically indicate the number of 'days over 35°C' as a particular mode of reporting increases in heat (see, e.g., Refs 3, 16, and 36). The basis and significance of this threshold is not clear, although it has been commonly used in city and state heatwave definitions. The threshold provided by the projections has also been adopted in assessments of climate change impacts on health in multiple reports and studies of Australia and its regions (see, e.g., Refs 37–39).

Problematized in terms of these ambient temperature thresholds, the projected increase in heat is striking, including for the monsoon tropics. Darwin, the capital of the Northern Territory, is reported as currently experiencing an average of 11 days per year above 35°C.[11] Depending on the Representative Concentration Pathways of greenhouse gasses used to generate the projection, this is projected to rise between 52 and 265 days of the year by 2090.[16] Using the same projections, Cairns (in northern Queensland) is expected to see an increase from the current average of 3 days over 35°C to between 5.5 and 48 in 2090. Broome (in northern Western Australia) is expected to increase from an average of 56 to between 95 and 231 days for 2090.[16]

These accounts assume that the 35°C threshold is significant and meaningful. Recent changes in the use of ambient temperature to designate a heatwave have avoided this assumption. Following a pilot service in 2014, the Australian Bureau of Meteorology (BoM) launched a Heatwave Service in 2015.[40] It defines heatwaves as 'three or more days of high maximum and minimum temperatures that are unusual for that location.'[41] Heatwave intensity is calculated as the excess heat factor (EHF), based on maximum and minimum daily temperatures specific to recent and historical temperatures at each location. EHF quantifies accumulating heat as a consequence of high minimum temperatures. Insufficient overnight cooling stores heat in the environment, providing for sustained heat exposure and rapid achievement of higher temperatures in the day that follows. The accumulated heat (above the local long-term threshold) and the recent acclimatization burden on the affected system (above a short-term threshold) are expected to progressively impact the adaptive limits of these systems. The systems in question here are both human and engineered systems which are understood to experience nonlinear challenges to adaptation as they encounter increasingly rare and intense heat for their location.[42]

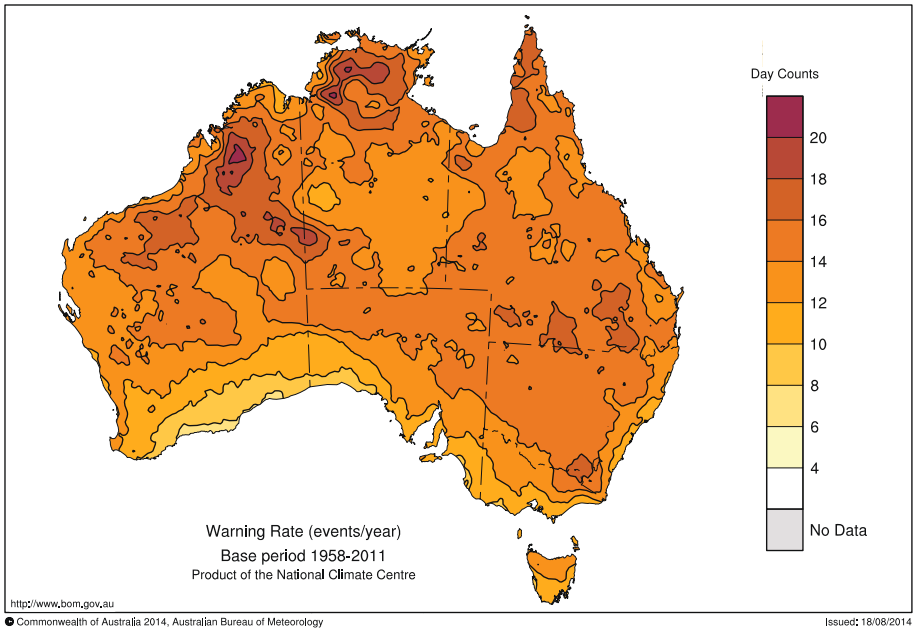

FIGURE 3 | 'Average annual number of Three Day Periods with positive EHF in the period 1958–2011.' (Reprinted with permission from Ref 41. Copyright 2015 Open access article distributed under the Creative Creative Commons Attribution License)

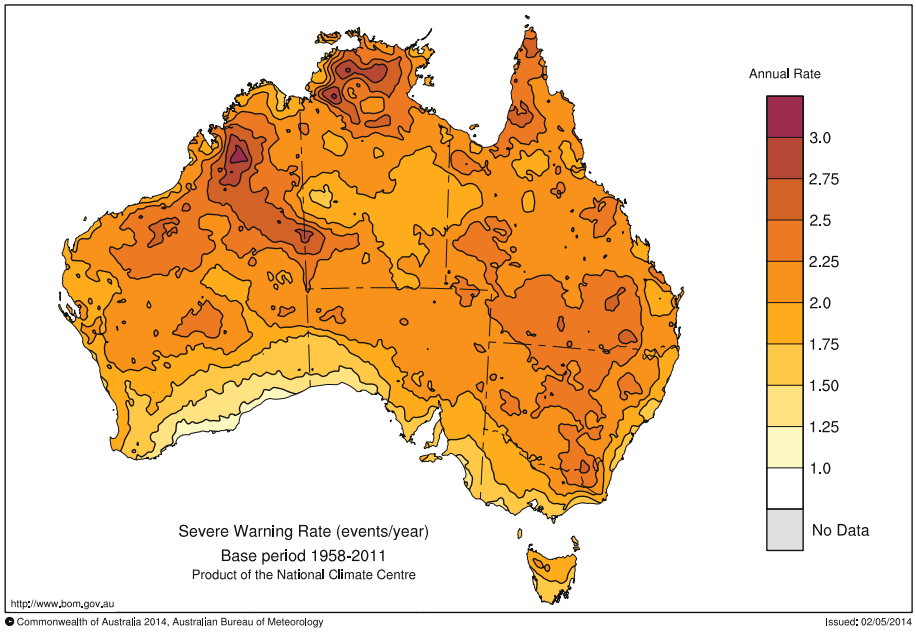

FIGURE 4 | 'Average annual occurrence of Three Day Periods (TDPs) with EHF above the severity threshold EHF85 in the period 1958–2011. Values are expressed in the form of TDPs per year.' (Reprinted with permission from Ref 41. Copyright 2015 Open access article distributed under the Creative Creative Commons Attribution License)

On the basis of this new definition, heatwaves and severe heatwaves (a distinction described in Part 2) occur most frequently in the far north of Australia—particularly in the Pilbara region of Western Australia, which sits across the tropical monsoon and arid climate zones, and the 'top end' of the Northern Territory within the tropical monsoon zone (see Figures 3 and 4, Ref. 41). These locations differ notably from locations in which extremely high daily ambient temperature maximums can occur, for which Figure 2 provides an example.

Humidity: A Sticky Problem in Accounting for Heat

Not all national systems account for extreme heat or heatwaves in terms of ambient temperature. For example, the United States' National Weather Service defines a heatwave as 'a period of abnormally and uncomfortably hot and unusually humid weather.'[43] In the US and Canada, there is regular use of bivariate metrics that include humidity and temperature in their account of heat, for example, the Heat Index in the US and Humidex (the 'Humidity Index') in Canada.[44–46] Such approaches include humidity on the basis that the amount of moisture in the air plays a significant role in the effectiveness of human thermoregulation in response to higher temperatures. In temperate conditions, thermoregulation is generally achieved through the dissipation of body heat by radiation and convection.[47] As ambient temperature increases and approaches that of the skin, the gradient for radiant heat loss diminishes, placing greater reliance on the evaporation of sweat to limit increases in body temperature.[48] However, in humid conditions, water vapor pressure reduces the evaporative capacity of the environment.[49] As such, the monsoon tropics not only limits the radiation and convection of body heat but also curtails evaporative heat loss due to the narrow water vapor pressure gradient between the sweat on the skin's surface and that of the humid air.[50] In this regard, warm to high ambient temperatures combined with high humidity present a substantial challenge for thermoregulation and therefore how 'hot' conditions are perceived to be by the human body.[18]

Public, informal discourse within Australia's tropical monsoon zone does identify humidity as significant in accounts of what kind of weather is 'hot' and associates these conditions with a range of health and wellbeing effects including fatigue and erratic behavior. 'Going troppo'[51] and 'mango madness'[52] (as mango season coincides with particularly hot and humid weather) colorfully characterize this account of heat. Although there is no bivariate metric commonly in use, the population does draw on weather information sources and news media in northern Australia, which provide humidity observations and ambient temperature observations as separate variables. BoM also

reports apparent temperature (AT) that represents the perception of ambient temperature adjusted for relative humidity and wind speed. While AT integrates meteorological variables into an easily understandable form, it is infrequently reported in mainstream weather reports, and there is no popular integration of heat and humidity into a single measure of heat, particularly not for the purpose of forecasting.

It is important to note that there are several ways in which environmental moisture can be accounted for in meteorological terms. (For a thorough analysis and comparison of indices, see Ref 53.) One commonly used metric, wet-bulb globe temperature (WBGT),[54] was developed explicitly to mitigate the risk of heat illness during physical exertion. WBGT is calculated by weighting the ambient temperature, the temperature of a wet bulb (indicative of relative humidity), and insolation. WBGT, like all thermal indices, has its limitations as a heat stress metric.[55] Nevertheless metrics like WBGT, which incorporate the significance of humidity for human thermoregulation, make the monsoon tropics visible as an area likely to cause heat stress. They also change the temporal geography of risk by designating the moderately hot and humid weather experienced for approximately half the year as significant for health.[56] Making insolation 'visible' through WBGT's calculation also contributes to the identification of heightened heat stress risk in the monsoon tropics, where proximity to the equator results in year-round exposure to high levels of solar radiation.

Such accounts of heat are not widely supported by public infrastructure or information services although BoM does provide WBGT observations for a number of locations nationally,[57] including in conjunction with guidance from Sports Medicine Australia for sport clubs and individuals who are physically active.[58] WBGT monitors are not commonly used, and in these cases BoM provides observed approximations of WBGT values, a calculation that assumes 'a constant "moderately sunny" day with "light winds"' rather than actual weather conditions. As such the WBGT values provided may underestimate or overestimate actual WBGT.[57] It should be noted that even where precise measurements are available, WBGT as an indice has been critiqued for its own relatively crude model of meteorological relationships as well as the fitness levels and clothing of populations it assumes.[55,59] Nonetheless, it is notable that, by including more elements in its account of environmental temperature than ambient temperature or even AT, and calculating their interaction in terms of what they mean for the body, WBGT presents quite a different problematization of heat.

Due to WBGT's problematization of daily conditions and its inclusion of additional elements intended to represent the functioning of the human body, WBGT assessment has been implemented in labor-intensive occupational settings including in the global tropical monsoon zone[56] and has been widely used by the US military[54] and in military settings across Australia.[60] Crucially, interpreting the weather through WBGT rather than ambient temperature means that the governance of what practices occur in the heat will be triggered in response to different variables and therefore produce governance interventions at different times, for different durations and in different places. An example of the alternative spatial and temporal geographies of dangerous 'heat' understood in terms of WBGT is demonstrated in Figure 5, which provides an example of mean monthly maximal WBGT for Australia.[61] The WBGT metric produces the tropical monsoon region as an area at risk for long periods of time, compared to the shorter variations in ambient temperature identified through an EHF approach. On the basis of the 'problem' of understanding heat in terms of the everyday functioning of bodily thermoregulation that WBGT assumes, it seems that when humidity levels are high and variable, the EHF approach could under or over-represent the risk to human health.

The EHF and WBGT problematizations thus identify different spaces and times as dangerous, shaped in part by different account of for what or whom heat is being identified. Utilizing other indices also produces quite dramatic shifts in the frequency of 'hot' conditions. The mainstream account of an ambient temperature of 35°C as a significant threshold for heat, and the average of 11 days a year that exceed it in Darwin (about 4% of the year[16]), appears in stark contrast to the account of how hot Darwin is in Guillaume et al.,[38] who incorporate humidity using Thom's Discomfort Index (DI) thresholds for historical weather data. They identified almost 75% of days per year were hot enough to have a 'high impact with most of the population feeling moderate to acute discomfort' (Ref 38, p. 19).

These different temporal and spatial accounts of heat stress risk also differently mobilize governmental interventions, such as public health and state emergency responses. There is no evidence to suggest WBGT or any other indice integrating humidity is being used by public health or state emergency services in the Northern Territory, Western Australia, or Queensland. This is in keeping with the fact such information is not readily available and yet these are the administrative regions which encounter the hot and humid conditions such indices enable to be calculated and communicated.

Indices including humidity also have a limited role in studies of climate change impacts,

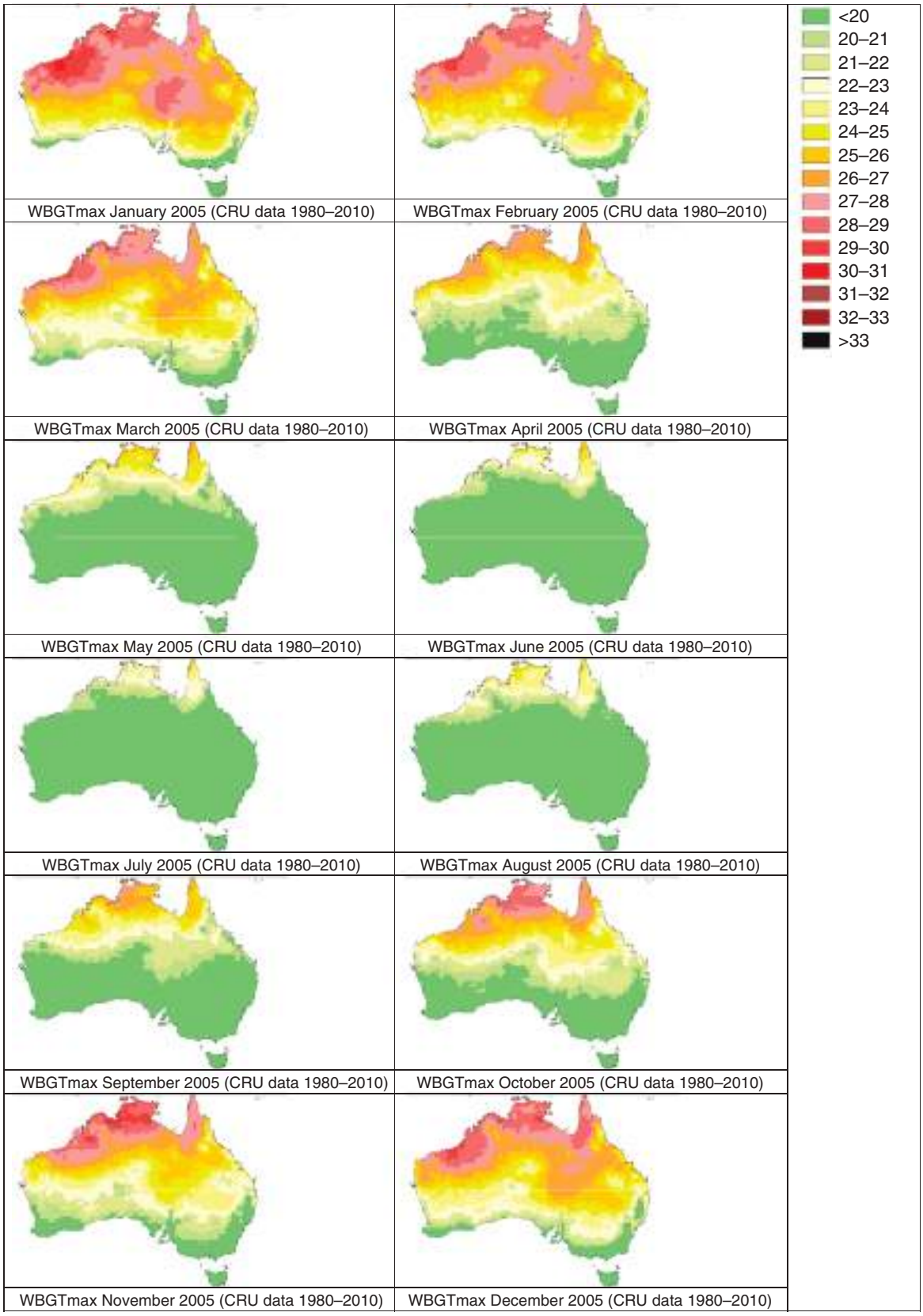

FIGURE 5 | Mean monthly maximal wet-bulb globe temperature for Australia (Climate Research Unit data 1980–2010), produced by ClimateCHIP.org through Hothaps-Soft tool.[61]

vulnerability, and adaptation in Australia. Some use them for historical vulnerability assessments but not for future projections.[5,38] For example, Guillaume et al.[38] demonstrated a wide divergence in the number of days that presented a risk to human health as a result of using DI, but defaulted to ambient temperature in considering climate change projections because of the limited reliability of humidity projections at the time. In climate change observations to date, temperature rises have resulted in stable relative humidity values in the Northern Territory.[62] With global absolute humidity also set to rise,[63] this relationship becomes more complicated, although for Australia's monsoon tropics the change in humidity may be fairly negligible.[64] The relative lack of certainty about humidity projections and the additional complexity of calculating how they relate to other variables has deterred many Australian climate change studies from assessing dangerous heat in ways that are more appropriate for human thermoregulation.

There are some examples in the international literature that demonstrate the inclusion of humidity in climate change projections.[63,65,66] There are also some arguments for understanding heat in terms of human thermoregulation and using WBGT metrics in Australia to account for potential climate change impacts on health[18,67] and better enable adaptation. Figure 6 below demonstrates the spatial and temporal distribution of extreme WBGT for the 2060s[68–70] and identifies the tropical monsoon zone globally, including Australia's monsoon tropics, as most at risk more often than temperate regions (including Australia's south). This again demonstrates where, when, and for whom different problematizations of heat can be seen to 'matter.'

Problematizing 'Dangerous' Heat in Terms of Populations and Bodies

As the WBGT metric demonstrates, understanding heat in terms of health assumes a human object—in addition to an environmental object—that needs to be known and measured. The Heatwave Service accounts for how heat might affect human populations and systems through applying a Generalized Pareto Distribution Function to the EHF in order to characterize heatwave severity. It fits this to each location's individual history of heatwave intensity to identify three different intensities of heat wave. (1) *Low-intensity heatwaves*, which account for 85% of heatwaves, are where adaptive strategies are expected to be effective for these more frequent, low-intensity events. This can be thought of as the Pareto effect. Juran and Godfrey[71] identified this part of the (heatwave intensity) population as the 'trivial many' and the subsequent population as the 'vital few.' (2) *Severe heatwaves* are identified as those that exceed this local intensity threshold. These are understood to challenge vulnerable people, particularly those with co-morbidity. (3) *Extreme heatwaves occur at* three-times the severity threshold. These are very rare and as such, it is understood that protective strategies are required for all people, with supporting

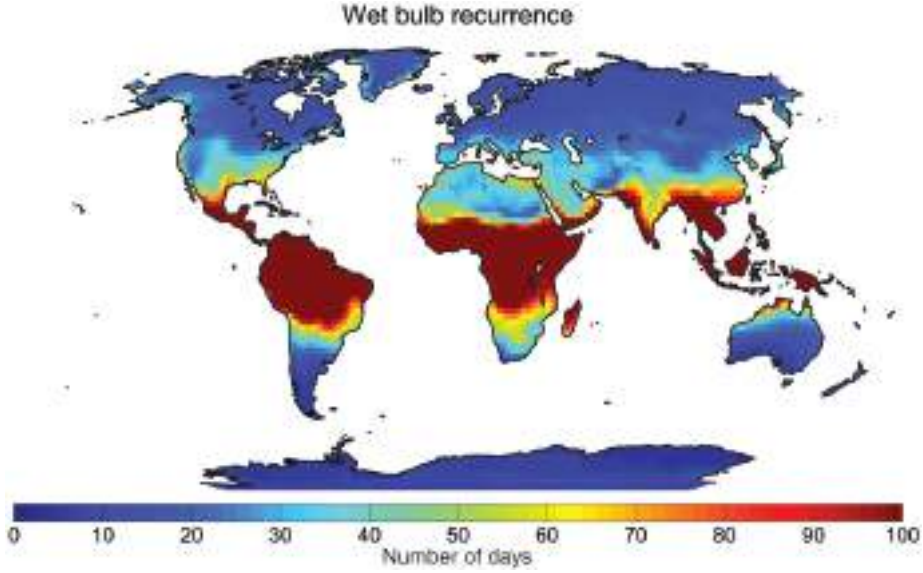

FIGURE 6 | How the number of days above an extreme wet-bulb temperature changed by the 2060s. (Reprinted with permission from Ref 68. Copyright 2016. Figure 3D, http://creativecommons.org/licenses/by/4.0/)

infrastructure and utilities occasionally failing in heat conditions beyond their design tolerance.

Epidemiological accounts of the relationship between heat and health, which take the local impact on morbidity and mortality as their starting point rather than applying a general model to environmental conditions, produce a slightly different account of weather conditions that are dangerous. Like the Heatwave Service, they take issue with simple thresholds in view of acclimatization to local conditions, but also with the failure to take into account 'location-specific temperatures that are known to elicit a response from existing populations' (Ref 5, p. 106). In effect, this challenges the assumed universal significance of the 35°C threshold, as well as the assumption of the universal thresholds associated with WBGT values, and the environmentally determined basis of the Heatwave Service.

Loughnan et al.[5] have developed location-specific temperature thresholds for all Australian state and territory capital cities to inform climate change adaptation policy. Of these, only Darwin is located in the tropical monsoon region. Significantly, and despite being exposed to higher average temperatures throughout the year, they identify mortality and morbidity thresholds in Darwin as *lower* than other Australian cities in temperate and sub-tropical zones, with a mean temperature threshold of 31°C, and a maximum temperature threshold of 36°C and 37°C for morbidity and mortality, respectively. These thresholds are significantly different to the previously assumed 35°C threshold. As we see below, these thresholds may be affected by other environmental variables, such as high humidity. Unfortunately, the report does not include Darwin in its final vulnerability assessment because of the poor correlation of the regionally downscaled climate model outputs with observed weather data. Nonetheless, they produce an alternative geography of heat and its dangerousness based on morbidity and mortality, which is in this sense a very 'human' geography of heat.

Significantly for the monsoon tropics, in their analysis of the location-specific temperature threshold for Darwin, Loughnan et al.[5] note that once humidity is factored in through AT, the mean ambient temperature threshold for morbidity and mortality jumps from 31°C to AT 35°C for morbidity and from 37°C to AT 47°C for mortality. By contrast, the other capital cities in temperate zones (e.g., Melbourne), may have higher ambient temperature thresholds than Darwin, but lower AT thresholds. This difference is not analyzed in detail in the report, but it would seem to indicate that threshold ambient temperatures that are later used for the vulnerability assessment to climate change are dangerous, at least in Darwin, because of their association with high humidity. Within natural science discourses of what constitutes heat as a problem, there is clearly a significant conversation here about how we account for the relationship between heat, humidity and health. In terms of governance, however, it is also significant that, whichever metric is used, different conditions become known as dangerous thus triggering (or not) health responses. In the monsoon tropics without an account of humidity, governance interventions to prevent morbidity and mortality may not be triggered at the right times. In the Darwin example, this might be where AT reaches 35°C, but ambient temperature is less than 31°C, both of which are very different to the generally assumed 35°C ambient temperature threshold and none of which necessarily relate to the EHF heatwave definition.

In combination with the (in)visibility of humidity and of the tropical monsoon zone as a distinctive region, problematizating heat in terms of the human reorients geographies of danger from the regions that are produced by environmental conditions to the places that become visible because of the impacts on human populations. However, implicit in this account is the human body itself, which is, of course, also problematized in multiple ways.[72] For example, thermal physiology, in its account of heat, considers not only environmental conditions (exogenous heat) but all sources of heat an individual is exposed to, including internal heat production (endogenous heat) due to physical exertion.[56,73] This effectively diversifies the understanding of what constitutes heat, including dangerous heat, and turns the activities or practices through which bodily heat is produced or stored into part of the 'problem.'[27] Such accounts inform work health and safety (WHS) discourses, with physical work, work outdoors, and/or in uncooled environments or with hot materials becoming part of a broader account of the heat that matters to the body.[74] Populations identified as particularly at risk work in agriculture, mining, construction, and maintaining critical infrastructure.[75–78]

In this way, thermal physiology creates yet another geography of heat, this time shaped by distributions of bodily exposure and exertion. Including in its problematization where and when work is done plays a role in recalibrating the locations of 'dangerous' heat in terms of the activities of outdoor and/or industrial workers, which includes young adults who are relatively fit.[18,56] This is in stark contrast to the epidemiological discourse of when and for whom extreme heat is problematic, which

tends to focus on heatwaves and the elderly population (see, e.g., Refs 79–82), but it is in keeping with research on heat stress and productivity, particularly in regions that experience prolonged periods of very hot weather.[83–89]

In the context of increasing environmental heat as a result of climate change, some of the most extensive explorations of workplace heat stress have occurred in conjunction with the HOTHAPS programme,[90,91] which is associated with a number of case studies, mostly in labor-intensive sectors in developing countries that fall within the global tropical and tropical monsoon zones.[85,88,92] In these studies, adaptive capacity is often understood as relatively limited. This is partly an effect of problematizing heat in terms of set work rates in response to WBGT values, but it is also shaped by problematizing climate change primarily in terms of impacts rather than adaptation. Thermal physiology discourses however indicate that the ability to change exposure, exertion, hydration, and active cooling serve as basic principles to manage heat rather than trying to reduce climate change impacts solely through mitigation, or through engineered environmental controls such as air-conditioning. The extent to which non-climatic elements and a number of practices and activities interact to shape exposure, exertion, and body heat storage, will affect the ways in which heat stress is governed and produced. Such complex accounts also provide a platform for a broader understanding of how adaptation can be enabled.[93–95] As such, *where* people are exposed, *who* is exposed, *how* and *why* opens out the spatial and temporal accounts of heat as a problem as well as the locations of governance interventions, including for climate change adaptation.

Summary

We have shown that different problematizations of heat produce very different temporal and spatial distributions of risk. Whether humidity is understood as significant for how heat affects human health seems to produce the monsoon tropics as either visible or not as a region that experiences dangerous heat. We have also seen that whether problematizations focus primarily on the environment, populations, or bodies in accounting for heat, and the elements they understand these to be made up of, also leads to very different geographies of risk—across places, populations, and practices—and associated governance strategies. The next section explores governance strategies for managing heat impacts on health with a particular focus on the tropical monsoon zone and the outdoor, manual workforce, in order to highlight the significance of these different understandings for everyday life in the region, which is already affected by climate change.

PART 2: IMPLICATIONS FOR THE MONSOON TROPICS

Governance and Adaptation in Australia's Tropical Monsoon Zone

Having identified humidity and the monsoon tropics as invisible in some problematizations of heat, it is no surprise that a multiplicity of approaches and lack of clarity pertains to the governance strategies pursued in the region. The national framework for protecting human health and safety during severe and extreme heat events[96] does note that there are 'regional differences' that need to be recognized, particularly in relation to the impact of humidity, although it offers little elaboration on this point. Others identify the 'tropics' as a particular region of concern. The Defence Community Organisation, for example, provides health advice about 'acclimatizing to the tropics' for Australian Defence Force employees and their families.[97] Below the federal level, within the three states and territories that fall across the monsoon tropics, there are various public health and other approaches to governing heat. Western Australia, the Northern Territory, and Queensland each have their own assortment of guidelines for managing extreme heat. Some of these recognize the specific issue of humidity. For example, the Northern Territory Department of Health has developed its own guidelines to prevent heat stress, which do highlight combined heat and humidity as a cause of heat stress during the wet season.[98] However, specific metrics or a means of identifying these conditions have not been identified or used to shape public health or other interventions. None of the jurisdictions at the time of writing had a specific management plan for extreme heat or heatwave impacts on health.

The limited governance of heat begs the question of what is being done to adapt to future climate change. Australia, including its tropical monsoon zone, has already experienced significant warming as a result of climate change.[99,100] As such, the distinction between contemporary systems of governance and the governance of adaptation is somewhat moot, at least in relation to the present day. In relation to how heat is problematized by climate change adaptation discourses, official projections are provided by

the 'Climate Change in Australia' website.[101] This produces climate projections in terms of NRM regions. How this might shape current governance or planned adaptation responses to increased heat is not yet clear. On the one hand, the ecologically defined NRM region of the Monsoonal North cuts across state/territory lines and corresponds fairly closely with the tropical monsoon zone where combined heat and humidity is significant for human health. This makes it easier to illustrate the regional particularity of climate change impacts on health. It also signals the potential to re-imagine health policy in terms of climatic zones and health impacts rather than administrative boundaries. On the other hand, the NRM projections, while trans-jurisdictional, are focused on NRM, and the published report on the Monsoonal North and Wet Tropics cluster says little about human health, with temperature reported separately from relative humidity. It also uses the 35°C ambient temperature thresholds when talking about heat and human populations, thereby occluding humidity as significant for impacts on health or the need for governance strategies attentive to this regional climatic difference.[16,102]

How heat is accounted for in climate projections adds a further dimension to the (in)visibility of different spatial and temporal geographies of danger. Thresholds beyond which coping or adapting becomes too difficult or too expensive[103] will be projected to occur sooner or later and in different locations depending on whether heat is understood to include humidity or not, or whether it is understood in terms of current morbidity and mortality thresholds rather than an ambient temperature threshold. How heat is problematized also affects the kinds of strategies that seem appropriate in both incremental and planned adaptation. For example, environmental heat, whether it includes only ambient temperature or other indices, can be governed through mitigation strategies to avoid certain global temperature thresholds.[104,105] If problematized in terms of population vulnerability this can produce governmentalities that seek to know environmental conditions and prepare medical services for statistically correlated impacts on health. Of course, if heat is *not* problematized as dangerous in a particular place or time then there are unlikely to be any planned adaptation strategies.[27]

The (in)visibility of the different forms of heat couples in a significant way with the general weakness of the climate change adaptation discourse within Australia, including in the three jurisdictions of the monsoon tropics, which have very little explicit policy in place in relation to how future climate might affect health.[3,62] Nonetheless, a number of extant policies, guidelines, and regulations do seek to govern the contemporary relationship between heat and health, across housing, public health, work health and safety/occupational health and safety. The following sections briefly review these policy areas in relation to the inclusion/exclusion of humidity and the (in)visibility of Australia's monsoon tropics and people and practices in the region.

Housing Design: Governing Buildings to Manage Exposure

One of the major adaptations to heat in the monsoon tropics is the widespread availability of air-conditioning. Houses constructed before the 1970s were typically high set, with frames built from local timber, and had breezy verandahs and undercroft spaces providing respite from summer heat.[106] These 'troppo' and 'Queenslander' housing styles[107–109] enabled thermal comfort through 'passive design' principles that promoted ventilation and air movement, with buildings oriented to reduce solar radiation.[110–112] Since the 1970s housing designs have incorporated air-conditioning, and the porous building envelopes of the past are now considered energy inefficient due to the number of 'leaks' which disperse air-conditioning to the environment outside.

In housing design, the impact of heat on human bodies is measured by assessing 'thermal comfort': a 'subjective' sensation that expresses a level of satisfaction with existing thermal conditions for the majority of the population (see Ref 113). Indoor thermal comfort is shaped by a number of factors, including air temperature, radiant temperature, humidity, air speed, and the type of clothing worn by building occupants (as well as the amount of physical activity being undertaken). Thermal comfort can be achieved in a number of ways (e.g., changing clothing and turning fans or air-conditioning on) but the passive design principles of the past are at odds with new national energy ratings schemes, which assume comfort is achieved through climate control which requires sealed buildings to work efficiently. As such, new suburban developments across the tropical monsoon zone tend to mimic temperate housing styles: these are comprised of tightly spaced, high thermal mass, or fully sealed buildings that have restricted opportunities for shading, such as having no eaves or space for vegetation.

A uniform one-size-fits-all national policy approach to housing and building codes has been critiqued for failing to provide the flexibility to cater to localized and regional climatic differences, particularly in tropical and sub-tropical regions. Figure 7,[114]

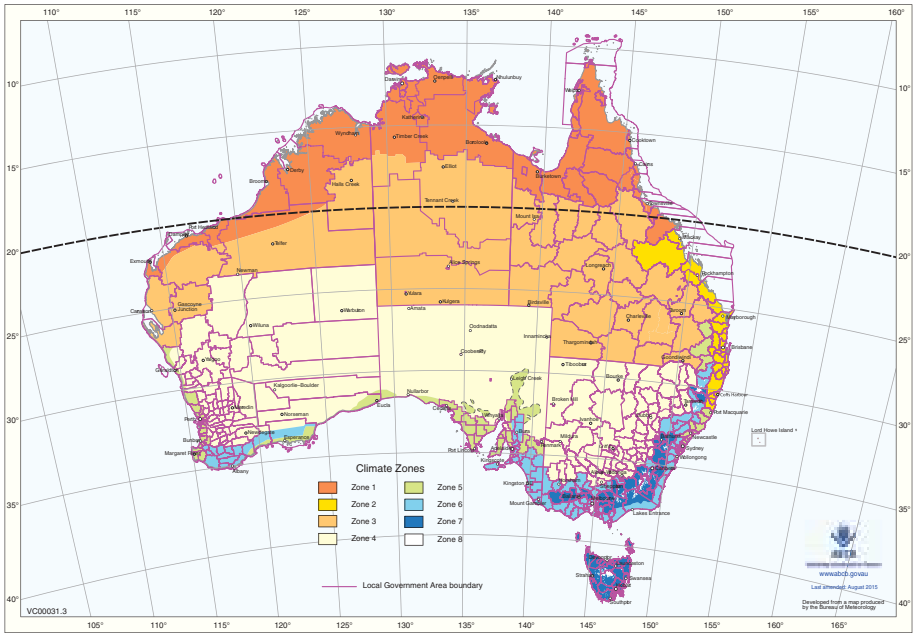

FIGURE 7 | Australian Building Codes Board (ABCB) climate zone map.[114]

the Australian Building Codes Board's (ABCB) Climate Zone Map, guides the energy efficiency Deemed-to-Satisfy Provisions in the National Construction Code. Although the map acknowledges that different design strategies are needed across eight different Australian climate zones, it should also be noted that the tropical monsoon zone—here termed climate zone 1 with a 'high humidity summer, warm winter'—is homogenous (despite important differences noted in Figures 2–5). It is yet another map of how heat is problematized in the monsoon tropics, however, and plays a role in governing how populations are exposed to heat.

Thermal comfort, even within climate zones, is temporally modulated by seasonal shifts. Within the tropical design discourse, passive design strategies are held to work well in the 'dry season' when there is a greater drop in nighttime temperatures and less humidity, but there is dispute over their effectiveness in the wet season where diurnal ranges are much narrower.[115] The conundrum is the desire to reconcile two 'opposing' thermal comfort parameters: the need for ventilation and air movement and the need to reduce hot and humid air during the height of the rainy/wet season.[111,116] As such, active cooling, such as air-conditioning, is often required to reduce humidity and heat stress during the 'build-up' and wet season, although it works less efficiently in tropical buildings that have more porous building envelopes. This dynamic adds another temporality to the account of heat and its governance through the materiality of housing as a proxy for managing heat effects on people, accounted for and measured through metrics of thermal comfort.

In accounting for heat in residential thermal comfort, differences again emerge in what variables are measured. While most agree on using variables such as internal/external air temperature and relative humidity, some also suggest including air velocity, metabolic rates, clothing types, and the important social dimensions of behavior adjustment, physiological acclimatization, and psychological habitation or expectation.[117–120] Australia's National House Energy Rating System (NatHERS) uses the effective temperature (ET) index, which uses a dry-bulb thermometer and excludes the measurement of humidity for assessing indoor thermal comfort. The ET formula is complicated, and includes many variables, so it was simplified and based on outdoor temperature—but this can only be used with relative humidity up to 50%. NatHERS then suggests mechanical cooling beyond what it deems to be 'typical' temperature ranges; in Darwin and Cairns this is given as 26.5°C.[121,122] Given that the average mean maximum temperature for Darwin has exceeded 26.5°C every month of the year over the period 1942–2015, and in Cairns this temperature is exceeded 10 months of the year over the same period,[123] this problematization seems to make little allowance for regional accounts of what conditions constitute 'hot' weather requiring air-conditioning, at least in a residential setting. Local populations might

consider hot and humid conditions as the trigger for air-conditioner use rather than ambient temperature, especially when the threshold is set so low. We see here how the (in)visibility of the tropical monsoon region, humidity, and different accounts of the degree and frequency of change over time, shapes and complicates the strategies being used to manage heat's relation to health through thermal comfort and housing design as one form of managing 'exposure.'

Public Health, Work Health and Safety: Governing People and Practices to Manage Exposure and Exertion

Building regulations and design accounts of thermal comfort only target the exposure of those who are indoors. Influential reviews of public health identify intersecting vulnerabilities including access to infrastructure such as air-conditioning and culture amongst other factors.[23,124] Those outdoors, such as the homeless or those working in the open air, are occluded from this housing-based problematization of heat and associated governance approach. This is not to say that such populations are not considered or governed in relation to heat elsewhere in different ways. For instance, epidemiological studies identifying population characteristics transgress issues of thermal comfort resulting from housing, although the association of public health with non-workplace activities tends to focus interventions on health services and households. Such studies tend to highlight the elderly and very young as most vulnerable, but in the monsoon tropics and northern Australia more broadly, they also highlight Indigenous populations as being at risk.[37,64]

As we saw in Part 1, problematizing heat as body heat resulting from exposure to environmental conditions and exertion shifts the focus to populations likely to engage in outdoor and/or labor-intensive activities. The monsoon tropics of Australia is characterized by a population is that it is relatively young, with a higher proportion of people employed in outdoor work from the mining industry to the military,[125] creating a working population that is chronically exposed to heat. As such a key question is: how do these sectors or industries problematize heat? And, does humidity or the monsoon tropics appear as significant in these problematizations, producing in turn particular populations, places, and practices for intervention?

There are several accounts of Australia's tropical monsoon region which note particular strain on outdoor or labor-intensive workers. [73,81,126,127] Such accounts have tended to focus not just on environmental conditions but also on exertion and exposure as areas of intervention. The Australian Defence Force for example articulates levels of exertion in relation to exposure through establishing recommended workload and work/rest cycles in relation to particular WBGT values.[128] For other labor-intensive industries, including those in the monsoon tropics, WHS policies follow a similar basic principle, typically recommending 'work to rest ratios,' 'down tools policies,' strategies to 'self-pace' or otherwise reduce work intensity and strategies such as 'rescheduling work so the hot tasks are performed during the cooler part of the day' (see, e.g., Refs 98 and 129). It should be noted of course that what constitutes 'hot' or 'cool' depends partly on how they account for environmental heat, as discussed in Part 1.

Here, the (in)visibility of humidity in the account of heat has a major effect on types of strategies pursued. From the limited data available, working at low to moderate intensities and self-pacing one's effort appear to prevent the development of heat illness in tropical conditions. Yet in the context of very hot ambient temperatures or chronically high WBGT, such strategies also provoke concern regarding lost productivity particularly under the substantial and ongoing increases in temperature as a result of climate change.[56] A similar issue occurs in relation to the focus on hydration in WHS heat stress management across Australia[130] including in the monsoon tropics.[131] Adequate hydration contributes positively to thermoregulation. In hot but relatively dry climates, the consumption of fluid in response to thirst combined with rest breaks in the shade may be sufficient to prevent excessively high core body temperatures. Yet in hot and humid environments that limit the potential for body heat dissipation, hydration and shaded rest breaks may not prevent the accumulation of body heat.[73] In these situations, while the prevention of dehydration can contribute to maintaining productivity and limit the development of heat stress, it does not provide immunity against the development of heat-related illness[132] or heat stroke.[133]

Accordingly, a more detailed understanding of thermal physiology in accounting for what constitutes heat indicates that exposure to hot and humid conditions requires hydration in conjunction with additional strategies to offset higher core body temperatures. Such strategies include cooling by water immersion,[134] exposure to airconditioned areas, application of cold towels, removal of personal protective equipment or clothing,[135] donning ice vests, and ingestion of crushed ice.[136] In practice however, the most commonly used method of outdoor cooling

is resting in the shade.[137] Here again, strategy choice for tropical regions is conflicted, with strategies appropriate for dry conditions promoted by dominant, national discourses within the tropical monsoon zone, producing slow cooling rates that in turn require extended duration of rest breaks.[138] In contrast, implementing the aforementioned cooling methods is likely to reduce the length of such periods. These accounts call for further research and interventions into cooling strategies as part of the governance of heat stress in the monsoon tropics, particularly in light of 'almost certain' rises in ambient temperature and WBGT[63,139] as a result of climate change.

As discussed in Part 1, some problematizations of heat treat the relationship between environmental conditions and health and productivity outcomes in a relatively linear fashion, focusing on impacts rather than causes of vulnerability through exposure and exertion or adaptive strategies that target these areas as well as hydration and cooling practices. Often, these impact-based modes of assessment are essential preliminary steps in making the case for governmental interventions or planned adaptation.[67,140–142] There are currently very few studies examining the sources of vulnerability or adaptive capacity in response to heat stress in the workforce in Australia's monsoon tropics. Carter and Muller[131] demonstrate the significance of hydration knowledge and behaviors at a mine site, and a recent paper by Jia et al.,[143] usefully examines organizational logics in relation to WBGT, noting that beliefs about the relationship between heat and productivity effectively mediates the relationship between heat and health. Such papers demonstrate the value of engaging at a more detailed level with practices of work in the region in order to account for how (body) heat emerges and how it might be better managed under current and future climate change.

DISCUSSION: THE (IN)VISIBILITY OF THE MONSOON TROPICS AND THE LABOR-INTENSIVE WORKFORCE

Different problematizations of heat produce different spatial and temporal geographies of danger, and associated targets of governance interventions and adaptation strategies. There are major divergences in how heat is understood between various disciplines and sectors. As such who is problematizing heat, for what purpose, and in relation to which technologies, ontologies, and analytical approaches, shapes what objects are taken to be the appropriate targets of measurement, assessment, and intervention. In relation to heat, we see these objects varying between environmental conditions (including just temperature or other variables such as humidity and various accounts of how temporal distributions matter) to health outcomes (such as morbidity and mortality, or bodily effects such as core body temperature shaped in part by exposure and exertion). Governance measures responding to these problematizations range from static accounts of vulnerability as a function of location to detailed interventions in practices, such as those in the workplace that manage cooling technologies and hydration rates.

Different accounts of what constitutes a heatwave also produce very different geographies of heat risk. In Australia, the dominant discourse of extreme heat presumes heatwaves to be of significance. In lay understandings, these are based on significant deviations from the average ambient temperature and do not factor in humidity. As a result, accounts of extreme heat in terms of how this feels for the human body, or over extensive periods of time, as well as accounts of heat that include humidity as significant, are occluded. Furthermore, the new official account of heatwaves in terms of EHF, which identifies much of the monsoon tropics as facing a higher incidence of extreme heat events, has not yet become part of the mainstream discourse. As such, there is a common assumption that heat is most likely to be dangerous where higher ambient temperatures occur, in the centre and south of the county. These different accounts produce conflicting geographies of risk. By contrast, the WBGT and EHF approaches, although based on very different metrics particularly in relation to humidity, both identify at least parts of the monsoon tropics as being at higher risk, but vary in the timing and duration of the periods they identify as dangerous.

These different spatial and temporal geographies are also produced by differing conceptualizations of the relationship *between* heat, health, and humidity. The relationship between heat and health differs between EHF and WBGT approaches. For the former, physiological adaptation a key concern, whereas WBGT assumes limits to physiological adaptation even of fit and healthy younger populations, and therefore calls for interventions to secure health at different times and frequencies. These differences are compounded by the exclusion of humidity from the EHF approach and its inclusion in WBGT-based approaches. There are currently calls to adopt the EHF as a 'national heatwave definition'[3,144] which, if linked to standards for triggering public health or workplace responses may obscure 'normally' hot and humid conditions that would be considered relatively

high risk under a WBGT approach, and which might also obscure the significance for bodily thermoregulation of periods when moderately high temperatures have remained relatively stable, but humidity has risen, or conversely, produce a heat wave warning where a significant rise in temperature is accompanied by a decline in humidity, such that the relative temperature was felt to be less severe. Such scenarios mean that the heatwave service runs the risk of being discredited as a basis for health interventions in the tropical monsoon zone when humidity fluctuates dramatically. This occurs particularly during the quite rapid shift between the wet and dry seasons.

In physical or material terms as well as in discursive terms, the significance of heat for the viability of social and economic systems in Australia's monsoon tropics should not be underestimated. In fact, a somewhat notorious antecedent to this discussion began in the early 20th century, in the context of racialized accounts of how bodies coped with heat and humidity. Then, how heat affected health was understood by some to be mediated by 'whiteness' and associated levels of cultural 'development.' This racial-climatic problematization of heat was rendered into a technology of governance in the form of Griffith Taylor's climograph in a bid to shape policies of settlement at the time. The climograph coupled the metrics of wet-bulb temperatures and relative humidity (associated with the Köppen scale) with designations of racially allocated thermal comfort in order to determine the most habitable locations for white settlers. Notably, the towns of the monsoon tropics such as Darwin, were designated as 'usually uncomfortable' or 'often uncomfortable' for white settlers.[145]

The climograph example demonstrates a fascinating divergence between the discourse of heat and its relationship to development between today and a century ago. The climograph ruled the monsoon tropics 'usually uncomfortable'[145] whereas the discourse of development for the region in 2017 completely occludes issues of heat and humidity in relation to both current and future conditions, and barely touches on climate change. Furthermore, this official discourse promotes all of Northern Australia, including the monsoon tropics, as Australia's new frontier for the expansion of industry, resource extraction, and agricultural activity.[146] This entails an attendant growth in the manual workforce that is likely to be exposed, and exerting themselves, in hot environmental conditions. Although not considered in this context, climate projections nevertheless indicate rapid increases in 'heat' as both ambient temperature and WBGT that puts the health and productivity of these workforces at risk.[16,63,99,147] Yet, the multiple problematizations of heat in play may actually sustain the northern development discourse by allowing for the invisibility of the tropical monsoon zone as well as its impact on the outdoor, manual workforce.

The presence of multiple problematizations and differences in their utility across sectors is not widely appreciated. In fact, the universalising nature of national discourses about heat in Australia, both in relation to the ambient temperature thresholds and more recently in the heat wave account of the Heatwave Service, occlude the value of more localized accounts of impacts that epidemiological studies provide and the ability to include regionally important variables such as humidity. The trend towards national or even international standards thus needs to be engaged with critically, as it may not always engender 'best practice' in particular climatic contexts. Such awareness should also be applied within climatic zones, with identification of more localized conditions, in terms of environmental conditions and their timing as well as the particular populations or practices in question, informing the account of heat.

It should be noted here that the visibility of the population of Australia's monsoon tropics and their role in producing national discourses about heat and health is quite limited. All of northern Australia accounts for only 1.1 million people, less than 5% of the national population.[148,149] This population is split across two states (Queensland and Western Australia) and one territory (the Northern Territory). All of three jurisdictions cover multiple climatic zones and as such, it is perhaps no surprise that the monsoon tropics has had little visibility in relation to national or state/territory level legislation and policy to date. Furthermore, with the exception of Darwin in the Northern Territory, the state capitals of Western Australia (Perth) and Queensland (Brisbane) are located in the most southern reaches of Australia's sub-tropical climates, and do not experience the hot and humid weather particular to the tropical monsoon region. This geographic distribution of economic and political power is replicated nation-wide with the majority of Australia's population living in temperate regions. As a result, problematizations of heat that identify long periods of moderately high temperatures and very high humidity as uncomfortable or even dangerous, and which account for the monsoon tropics as a distinct climatic zone per se, appear distant, unfamiliar, and fragmented to mainstream Australia, and of primary importance to a small population with little power to dramatically shift the dominant national discourse.

A significant gap in this critical analysis has been the consideration of Indigenous problematizations of heat and associated governance strategies. A key feature of northern Australia is that 15% of its population is Indigenous.[148] Cultural and social practices, including land-use practices, language, and ritual are strong in the region, particularly in the more remote localities. However, little is known in the academic literature or by policy-makers about Indigenous ontologies of heat or practices that regulate it. These are likely to be particularly important because of the complex and profound ways in which land, weather, and ceremonial practices are deeply embedded in Indigenous ontologies of health.[37] A better understanding of this area by non-Indigenous policy-makers requires quality research with Indigenous knowledge authorities. However, the significance of such work also lies in understanding how dominant and Indigenous problematizations of heat relate, requiring careful ontological work to design culturally, as well as climatically, appropriate governance interventions and adaptation strategies.[150–153]

CONCLUSION

Heat is problematized in multiple ways in relation to human health within and between the domains and disciplines of weather information services and climate projections, epidemiology and thermal physiology, WHS, public health, and building design. In Australia, dominant discourses of significant temperature thresholds in accounts of extreme weather and climate information implicitly and explicitly focus on ambient temperature, and more recently its variation from local mean temperatures. Alternative accounts of which environmental conditions constitute heat in terms of their significance for human health also include some measure of humidity, and may also include human activity or other health characteristics as a factor in whether these conditions are 'dangerous' or not.

These different conceptual inclusions and exclusions produce different spatial and temporal geographies of dangerous heat, ranging from: the (in)visibility of humidity and the monsoon tropics as a particular climatic zone and as a region of where heat could be dangerous; significant differences in the temporal scales and patterns of risk, either appearing not to be at risk at all, occurring as infrequent deviations from recent mean temperatures, or occurring on a seasonal or even daily basis; the (in)visibility of exposed populations working outdoors or in manual roles.

What places, populations and practices these problematizations of heat make visible—or not—has significant implications for where governance is targeted, and through what strategies, tactics, and technologies it is deployed. These may be as large scale as the inclusion or exclusion of particular regions for settlement and development or as small scale as decisions about which strategies to manage body temperature are most effective in particular regions. Adaptation strategies and outcomes are also produced through the intersection of geographies of physical effects and governance responses. In this respect, the (in)visibility of humidity in accounts of heat in projections data will be particularly significant in producing diverging projections of the geography of climate change impacts, including their speed and duration. Planned adaptation strategies in particular will be significantly shaped by which problematization holds sway in the dominant national discourse and the discourses within disciplines, sectors, and jurisdictions. Occluding certain populations or variables from calculation could jeopardize the effectiveness or appropriateness of adaptation strategies. This review has highlighted the (in)visibility of the monsoonal north, humidity and the outdoor, manual workforce, as particular points of contention. How these inclusions and occlusions play out in lived, material ways is of serious concern, and is in need of further research and more carefully considered policy approaches.

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REFERENCES

1. Coates L, Haynes K, O'Brien J, McAneney J, de Oliveira FD. Exploring 167 years of vulnerability: an examination of extreme heat events in Australia 1844–2010. *Environ Sci Policy* 2014, 42:33–44.

2. Guest C, Wilson K, Woodward AJ, Hennessy K, Kalkstein L, Skinner C, McMichael AJ. Climate and mortality in Australia: retrospective study, 1979–1990, and predicted impacts in five major cities in 2030. *Clim Res* 1999, 13:1–15.
3. Hughes L, Hanna E, Fenwick J. *The Silent Killer: Climate Change and the Health Impacts of Extreme Heat*. Sydney: Climate Council of Australia; 2016.
4. Schaffer A, Muscatello D, Broome R, Corbett S, Smith W. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. *Environ Health* 2012, 11:3.
5. Loughnan M, Tapper N, Phan T, Lynch K, McInnes J. *A Spatial Vulnerability Analysis of Urban Populations During Extreme Heat Events in Australian Capital Cities*. Gold Coast: National Climate Change Adaptation Research Facility; 2013, 128.
6. Yu W, Mengersen K, Hu W, Guo Y, Pan X, Tong S. Assessing the relationship between global warming and mortality: lag effects of temperature fluctuations by age and mortality categories. *Environ Pollut* 2011, 159:1789–1793.
7. Nitschke M, Tucker GR, Hansen AL, Williams S, Zhang Y, Bi P. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environ Health* 2011, 10:10.1186.
8. Williams S, Nitschke M, Sullivan T, Tucker GR, Weinstein P, Pisaniello DL, Parton KA, Bi P. Heat and health in Adelaide, South Australia: assessment of heat thresholds and temperature relationships. *Sci Total Environ* 2012, 414:126–133.
9. Nitschke M, Tucker GR, Bi P. Morbidity and mortality during heatwaves in metropolitan Adelaide. *Med J Aust* 2007, 187:662–665.
10. Tong S, Wang XY, Barnett AG. Assessment of heat-related health impacts in Brisbane, Australia: comparison of different heatwave definitions. *PLoS One* 2010, 5:e12155.
11. Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The effect of heatwaves on mental health in a temperate Australian city. *Epidemiology* 2008, 19:S85.
12. Berry HL, Bowen K, Kjellstrom T. Climate change and mental health: a causal pathways framework. *Int J Public Health* 2010, 55:123–132.
13. Anderson CA. Heat and violence. *Curr Direct Psychol Sci* 2001, 10:33–38.
14. Xiang J, Bi B, Pisaniello D, Hansen A, Sullivan T. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010. *Occup Environ Med* 2014, 71:246–252.
15. Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST. Heat stress causes substantial labour productivity loss in Australia. *Nat Clim Change* 2015, 5:647–651.
16. Moise A, Abbs D, Bhend J, Chiew F, Church J, Ekström M, Kirono D, Lenton A, Lucas C, McInnes K, et al. Monsoonal north cluster report. In: *Climate Change in Australia Projections for Australia's Natural Resource Management Regions*: Cluster Reports; 2015.
17. Perkins SE, Argüeso D, White CJ. Relationships between climate variability, soil moisture, and Australian heatwaves. *J Geophys Res Atmos* 2015, 120:8144–8164.
18. Hanna EG, Kjellstrom T, Bennett C, Dear K. Climate change and rising heat: population health implications for working people in Australia. *Asia Pac J Public Health* 2011, 23:14S–26S.
19. Woodruff RE, McMichael T, Butler C, Hales S. Action on climate change: the health risks of procrastinating. *Aust N Z J Public Health* 2006, 30:567–571.
20. McMichael A, Woodruff R, Whetton P, Hennessy K, Nicholls N, Hales S, Woodward A, Kjellstrom T. *Human health and climate change in Oceania: a risk assessment*. Canberra: Commonwealth Department of Health and Ageing; 2003.
21. Daudt HM, Cv M, Scott SJ. Enhancing the scoping study methodology: a large, inter-professional team's experience with Arksey and O'Malley's framework. *BMC Med Res Methodol* 2013, 13:9.
22. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Inf Libr J* 2009, 26:91–108.
23. Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health* 2008, 29:41–55.
24. Flynn TR. *Satre, Foucault, and Historical Reason: A Poststructuralist Mapping of History*, vol. 2. Chicago: University of Chicago Press; 2005.
25. Bacchi C. Why study problematizations? Making politics visible. *Open J Polit Sci* 2012, 2:1.
26. Shove E. *Comfort, Cleanliness and Convenience: The Social Organization of Normality (New Technologies/New Cultures)*. Oxford: Berg; 2004.
27. Oppermann E, Spencer M, Brearley M. Emotional athletes, brainy workers and other hot new developments. *Learn Commun* 2015, 15:32–39.
28. Foucault M. *The Will to Knowledge: The History of Sexuality Volume One*. London: Penguin Books; 1998.
29. Dean M. *Governmentality: Power and Rule in Modern Society*. London: Sage; 2010.

30. Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. *Hydrol Earth Syst Sci Discuss* 2007, 4:439–473.

31. Stephens A, Oppermann E, Turnour J, Brewer T, O'Brien C, Rayner T, Blackwood G, Dale A. Identifying tensions in the development of northern Australia: implications for governance. *J Econ Soc Policy* 2015, 17:5.

32. Bureau of Meteorology. Climate classification maps. Available at: http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp?maptype=tmp_zones-maps. (Accessed May 5, 2015).

33. Carlucci S, Pagliano L. A review of indices for the long-term evaluation of the general thermal comfort conditions in buildings. *Energ Buildings* 2012, 53:194–205.

34. Australian Bureau of Meteorology. Maximum Temperature °C, 11th January 2017. Available at: www.bom.gov.au/jsp/awap/temp/index.jsp. (Accessed January 21, 2017).

35. South Australian State Emergency Service. *Extreme Heat Arrangements: Annex A to Extreme Weather Hazard Plan*. Adelaide: South Australian State Emergency Service; 2010.

36. Hennessy K, Page C, McInnes K, Walsh K, Pittock B, Bathols J, Suppiah R. *Climate Change in the Northern Territory: Consultancy Report for the Northern Territory Department of Infrastructure, Planning and Environment*. Aspendale: CSIRO; 2004.

37. Green DL. *Climate Change and Health: Impacts on Remote Indigenous Communities in Northern Australia*. Aspendale: CSIRO; 2006.

38. Guillaume J, Li G, Hutchinson M, Proust K, Dovers S. A differential vulnerability assessment of climate change impacts on Darwin. In: *The Integrated Assessment of Climate Change Impacts on Urban Settlements (IACCIUS) Project*; 2010.

39. Steffen W, Hughes L, Perkins S. *Heatwaves: Hotter, Longer, More Often*. Sydney: Climate Council of Australia; 2014.

40. Bureau of Meteorology. About pilot heatwave forecast. Available at: http://www.bom.gov.au/weather-services/about/heatwave-forecast.shtml. (Accessed May 5, 2015).

41. Nairn JR, Fawcett RJ. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. *Int J Environ Res Public Health* 2015, 12:227–253.

42. Ziser C, Dong Z, Saha T. Investigation of weather dependency and load diversity on queensland electricity demand. In: *Australasian Universities Power Engineering Conference 2005, AUPEC 2005*; 2005.

43. National Oceanic and Atmospheric Administration's National Weather Service. Glossary. Available at: http://w1.weather.gov/glossary/index.php?letter=h. (Accessed May 5, 2016).

44. Smoyer-Tomic K, Kuhn R, Hudson A. Heat wave hazards: an overview of heat wave impacts in Canada. *Nat Hazards* 2003, 28:465–486.

45. Quandt SA, Wiggins MF, Chen H, Bischoff WE, Arcury TA. Heat index in migrant farmworker housing: implications for rest and recovery from work-related heat stress. *Am J Public Health* 2013, 103:e24–e26.

46. d'Ambrosio Alfano FR, Palella BI, Riccio G. Thermal environment assessment reliability using temperature-humidity indices. *Ind Health* 2011, 49:95–106.

47. Galloway S, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc* 1997, 29:1240–1249.

48. Mitchell D, Senay L, Wyndham C, van Rensberg A, Rogers G, Strydom N. Acclimatization in a hot, humid environment: energy exchange, body temperature, and sweating. *J Appl Physiol* 1976, 40:768–778.

49. Berglund LG, Gonzalez RR. Evaporation of sweat from sedentary man in humid environments. *J Appl Physiol* 1977, 42:767–772.

50. Moyen NE, Ellis CL, Ciccone AB, Thurston TS, Cochrane KC, Brown LE, Coburn JW, Judelson DA. Increasing relative humidity impacts low-intensity exercise in the heat. *Aviat Space Environ Med* 2014, 85:112–119.

51. Lobo M. Racialised bodies encounter the city: 'Long Grassers' and asylum seekers in Darwin. *J Intercult Stud* 2013, 34:454–465.

52. Cloonan D. You'll never never know, if you never never go. *Psychother Aust* 1998, 4:42–47.

53. Blazejczyk K, Epstein Y, Jendritzky G, Staiger H, Tinz B. Comparison of UTCI to selected thermal indices. *Int J Biometeorol* 2012, 56:515–535.

54. Yaglou CP, Minard D. Control of heat casualties at military training centers. *Arch Ind Health* 1957, 16:302–305.

55. d'Ambrosio Alfano FR, Malchaire J, Palella BI, Riccio G. The WBGT index revisited after 60 years of use. *Ann Occup Hyg* 2014, 58:955–970.

56. Brearley M, Harrington P, Lee D, Taylor R. Working in hot conditions—a study of electrical utility workers in the Northern Territory of Australia. *J Occup Environ Hyg* 2015, 12:156–162.

57. Bureau of Meteorology. Thermal comfort observations. Available at: www.bom.gov.au/info/thermal_stress/. (Accessed April 19, 2017).

58. Sports Medicine Australia. Hot weather guidelines for sporting clubs and associations and the physically active. Available at: http://sma.org.au/wp-content/uploads/2009/05/hot-weather-guidelines-web-download-doc-2007.pdf. (Accessed May 5, 2016).

59. Budd GM. Wet-bulb globe temperature (WBGT) – its history and its limitations. *J Sci Med Sport* 2008, 11:20–32.
60. Cotter JD, Roberts WS, Amos D, Lau W-M, Prigg SK. Soldier performance and heat strain during evaluation of a combat fitness assessment in Northern Australia; 2000.
61. Lemke B, Kjellstrom T. WBGT maximum values 2005 using Climate Research Unit Data 1980-2010. Available at: http://climatechip.org/hothaps-software. (Accessed January 16, 2017).
62. AECOM. *Supporting Evidence-Based Adaptation Decision-MAKING in the Northern Territory: A Synthesis of Climate Change Adaptation Research*. Gold Coast: National Climate Change Adaptation Research Facility; 2013, 93.
63. Dunne JP, Stouffer RJ, John JG. Reductions in labour capacity from heat stress under climate warming. *Nat Clim Change* 2013, 3:563–566.
64. Goldie J, Sherwood SC, Green D, Alexander L. Temperature and humidity effects on hospital morbidity in Darwin, Australia. *Ann Glob Health* 2015, 81:333–341.
65. Lemke B, Kjellstrom T. Calculating workplace WBGT from meteorological data: a tool for climate change assessment. *Ind Health* 2012, 50:267–278.
66. Parsons K. Occupational health impacts of climate change: current and future ISO standards for the assessment of heat stress. *Ind Health* 2013, 51:86–100.
67. Hanna EG, Spickett JT. Climate change and human health: building Australia's adaptation capacity. *Asia Pac J Public Health* 2011, 23:7S–13S.
68. Horton RM, Mankin JS, Lesk C, Coffel E, Raymond C. A review of recent advances in research on extreme heat events. *Curr Clim Change Rep* 2016, 2:242–259.
69. Coffel E. Heat stress and societal impacts in the 21st century. In: *2015 AGU Fall Meeting*. Malden, MA: AGU Publications; 2015.
70. Thompson A. Heat, humidity combine to threaten millions in future. Available at: http://www.climatecentral.org/news/heat-humidity-threaten-millions-in-future-19815. (Accessed December 17, 2015).
71. Juran J, Godfrey A, eds. *Juran's Quality Handbook*. 5 ed. New York: McGraw-Hill; 1999.
72. Mol A. *The Body Multiple: Ontology in Medical Practice*. Durham: Duke University Press; 2002.
73. Brearley M, Norton I, Rush D, Hutton M, Smith S, Ward L, Fuentes H. Influence of chronic heat acclimatisation on occupational thermal strain in tropical field conditions. *J Occup Environ Med* 2016, 58:1250–1256.
74. Lao J, Hansen A, Nitschke M, Hanson-Easey S, Pisaniello D. Working smart: an exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. *Saf Sci* 2016, 82:228–235.
75. Donoghue AM, Sinclair MJ, Bates GP. Heat exhaustion in a deep underground metalliferous mine. *Occup Environ Med* 2000, 57:165–174.
76. Jackson LL, Rosenberg HR. Preventing heat-related illness among agricultural workers. *J Agromed* 2010, 15:200–215.
77. Srinavin K, Mohamed S. Thermal environment and construction workers' productivity: some evidence from Thailand. *Build Environ* 2003, 38:339–345.
78. Gubernot D, Anderson GB, Hunting K. The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. *Int J Biometeorol* 2014, 58:1779–1788.
79. Bethea D, Parsons K. *The Development of a Practical Heat Stress Assessment Methodology for Use in UK Industry*. Norwich: Crown Copyright; 2002, 200.
80. Khalaj B, Lloyd G, Sheppeard V, Dear K. The health impacts of heat waves in five regions of New South Wales, Australia: a case only analysis. *Int Arch Occup Environ Health* 2010, 83:833–842.
81. Peiffer JJ, Abbiss CR. Thermal stress in North Western Australian iron ore mining staff. *Ann Occup Hyg* 2013, 57:519–527.
82. Xiang J, Bi P, Pisaniello D, Hansen A. The impact of heatwaves on workers' health and safety in Adelaide, South Australia. *Environ Res* 2014, 133:90–95.
83. Dash SK, Kjellström T. Workplace heat stress in the context of rising temperature in India. *Curr Sci* 2011, 101:496–503.
84. Jay O, Kenny GP. Heat exposure in the Canadian workplace. *Am J Ind Med* 2010, 53:842–853.
85. Sahu S, Sett M, Kjellstrom T. Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. *Ind Health* 2013, 51:424–431.
86. Cortez OD. Heat stress assessment among workers in a Nicaraguan sugarcane farm. *Glob Health Action* 2009, 2:65–70.
87. Spector JT, Krenz J, Rauser E, Bonauto DK. Heat-related illness in Washington state agriculture and forestry sectors. *Am J Ind Med* 2014, 57:881–895.
88. Crowe J, Wesseling C, Solano BR, Umaña MP, Ramírez AR, Kjellstrom T, Morales-Hidalgo D, Nilsson M. Heat exposure in sugarcane harvesters in Costa Rica. *Am J Ind Med* 2013, 56:1157–1164.
89. Tawatsupa B, Yiengprugsawan V, Kjellstrom T, Berecki-Gisolf J, S-a S, Sleigh A. Association between heat stress and occupational injury among Thai workers. *Ind Health* 2013, 51:34–46.

90. Kjellstrom T, Kovats RS, Lloyd SJ, Holt T, Tol RSJ. The direct impact of climate change on regional labor productivity. *Arch Environ Occup Health* 2009, 64:217–227.
91. Kjellstrom T, Gabrysch S, Lemke B, Dear K. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. *Glob Health Action* 2009, 2:2082–2089.
92. Tawatsupa B, Yiengprugsawan V, Kjellstrom T, S-A S, Sleigh A, Team tTCS. Heat stress, health and well-being: findings from a large national cohort of Thai adults. *BMJ Open* 2012, 2. https://doi.org/bmjopen.bmj.com/content/2/6/e001396.
93. Banwell C, Dixon J, Bambrick H, Edwards F, Kjellstrom T. Socio-cultural reflections on heat in Australia with implications for health and climate change adaptation. *Glob Health Action* 2012, 5:1–9.
94. Maller CJ, Strengers Y. Housing, heat stress and health in a changing climate: promoting the adaptive capacity of vulnerable households, a suggested way forward. *Health Promot Int* 2011, 26:492–498.
95. Strengers Y, Maller C. Integrating health, housing and energy policies: social practices of cooling. *Building Res Inf* 2011, 39:154–168.
96. PricewaterhouseCoopers Australia. *Protecting Human Health and Safety During Severe and Extreme Heat Events*: a national framework. Canberra: PriceWaterhouseCoopers Australia; 2011.
97. Defence Community Organisation. *Welcome to Darwin*. Canberra: Defence Community Organisation on behalf of the Department of Defence, Australian Government, Commonwealth of Australia; 2011.
98. Department of Health. *Guidelines to Prevent Heat Stress*. Darwin: Northern Territory Government; 2011.
99. Hyatt OM, Lemke B, Kjellstrom T. Regional maps of occupational heat exposure: past, present, and potential future. *Glob Health Action* 2010, 3.
100. Nicholls N, Collins D. Observed climate change in Australia over the past century. *Energy Environ* 2006, 17:1–12.
101. Commonwealth Scientific and Industrial Research Organisation. Climate change in Australia. Available at: http://www.climatechangeinaustralia.gov.au/en/. (Accessed May 20, 2016).
102. Commonweatlth Scientific and Industrial Research Organisation. Climate change in Australia projections for Australia's NRM regions: Northern Australia projection summaries. Available at: http://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/super-clusters/?current=NSC&popup=true&tooltip=true. (Accessed May 20, 2016).
103. Sherwood SC, Huber M. An adaptability limit to climate change due to heat stress. *Proc Natl Acad Sci USA* 2010, 107:9552–9555.
104. Shaw C. Choosing a dangerous limit for climate change: public representations of the decision making process. *Glob Environ Change* 2013, 23:563–571.
105. Liverman DM. Conventions of climate change: constructions of danger and the dispossession of the atmosphere. *J Hist Geogr* 2009, 35:279–296.
106. Fantin S, Allwood B, Law L. Design for climate change: tropical Australia. *Sanctuary* 2015, 30:83–85.
107. Goad P, Bingham-Hall P. *Troppo: Architecture for the Top End*. Balmain: Pesaro Publishing; 1999.
108. Bridgman D. The Anglo-Asian bungalow in Australia's Northern Territory. In: Leach A, Moulis A, Sully N, eds. *Shifting Views: Selected Essays on the Architectural History of Australia and New Zealand*. St Lucia: University of Queensland Press; 2009, 167–177.
109. Naylor S. The ethos of "the Queenslander": a journey into the art of building in north Queensland. *etropic: Electron J Stud Tropics* 2010, 9:1–10.
110. Aynsley R. Indoor wind speed coefficients for estimating summer comfort. *Int J Vent* 2006, 5:3–12.
111. Kane A, Fuller RJ, Luther MB, Boldys R. ANZSES 2009: proceedings of the solar 2009 the 47th ANZSES annual conference. In: *ANZSES Conference (47th : 2009 : Townsville, Queensland)*. Townsville: ANZSES; 2009.
112. Cheng V, Ng E, Givoni B. Effect of envelope colour and thermal mass on indoor temperatures in hot humid climate. *Solar Energy* 2005, 78:528–534.
113. Raja IA, Nicol JF, McCartney KJ, Humphreys MA. Thermal comfort: use of controls in naturally ventilated buildings. *Energ Buildings* 2001, 33:235–244.
114. ABCB. Climate zone map. 2015. Available at: http://www.abcb.gov.au/Resources/Tools-Calculators/Climate-Zone-Map-Australia-Wide. (Accessed January 21, 2017).
115. Tenorio R. Dual mode cooling house in the warm humid tropics. *Solar Energy* 2002, 73:43–57.
116. Law L, Safarova S, Campbell A, Halawa E. Design for liveability in tropical Australia. In: Wallace R, Harwood S, Gerritson R, Prideaux B, Brewer T, Rosenman L, Dale A, eds. *Rethinking Northern Australian Development*. Canberra: ANU Press. Forthcoming.
117. Fanger PO. Thermal environment – human requirements. *Environmentalist* 1986, 6:275–278.
118. de Dear R, Brager GS. Developing an adaptive model of thermal comfort and preference. *ASHRAE Trans* 1998, 104:145–167.

119. Halawa E, Jv H. The adaptive appraoch to thermal comfort: a critical overview. *Energ Buildings* 2012, 51:101–110.
120. Kenawy I, Elkadi H. Diversity and thermal comfort in outdoor places. *Int J Divers Organ Commun Nations* 2011, 11:237–248.
121. Safarova S. Cairns tropical houses: assessing passive design and energy efficiency in the current Australian policy context. Centre for Tropical Urban and Regional Planning, James Cook University 2013, Master of Applied Science (Tropical Urban and Regional Planning).
122. Delsante A. Is the new generation of building energy rating software up to the task? A review of AccuRate. In: *ABCB Conference Building Australia's Future 2005*; 2005. Available at: http://www.hearne.software/getattachment/78171784-d295-4305-a0bc-341258fee23d/AccuRate-Reviewer-s-Guide.aspx. (Accessed June 26, 2016).
123. Bureau of Meteorology. Climate data services. Available at: http://www.bom.gov.au/climate/data/. (Accessed June 23, 2016).
124. Hatvani-Kovacs G, Belusko M, Skinner N, Pockett J, Boland J. Drivers and barriers to heat stress resilience. *Sci Total Environ* 2016, 571:603–614.
125. Department of Education Employment and Workplace Relations. *Australian Jobs 2013*. Canberra: Department of Education Employment and Workplace Relations; 2013, 44.
126. Brearley M, Norton I, Trewin T, Mitchell C. *Fire Fighter Cooling in Tropical Field Conditions*. Darwin: National Critical Care and Trauma Response Centre; 2011.
127. Maté J, Oosthuizen J. Global warming and heat stress among Western Australian mine, oil and gas workers. In: Oosthuizen J, ed. *Environmental Health – Emerging Issues and Practice*. Croatia: InTech; 2012, 289–305.
128. Hunt AP, Billing DC, Patterson MJ, Caldwell JN. Heat strain during military training activities: the dilemma of balancing force protection and operational capability. *Temperature* 2016, 3:307–317.
129. Workplace Health and Safety Queensland. Working in heat – advice about how to prevent heat illness from working outdoors in hot weather or where heat is generated as part of work. 2013. Available at: https://web-beta.archive.org/web/20160322005901/https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0009/82962/working-in-heat-factsheet.pdf. (Accessed April 19, 2017).
130. Xiang J, Hansen A, Pisaniello D, Bi P. Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia. *PLoS One* 2015, 10:e0135040.
131. Carter A, Muller R. Hydration knowledge, behaviours and status of staff at the residential camp of a fly-in/fly-out minerals extraction and processing operation in tropical north Australia. *Ind Health* 2007, 45:579–589.
132. Cuddy JS, Ruby BC. High work output combined with high ambient temperatures caused heat exhaustion in a wildland firefighter despite high fluid intake. *Wilderness Environ Med* 2011, 22:122–125.
133. Carter R III, Cheuvront SN, Williams JO, Kolka MA, Stephenson LA, Sawka MN, Amoroso PJ. Epidemiology of hospitalizations and deaths from heat illness in soldiers *Med Sci Sports Exerc* 2005, 37:1338–1344.
134. Walker A, Driller M, Brearley M, Argus C, Rattray B. Cold-water immersion and iced-slush ingestion are effective at cooling firefighters following a simulated search and rescue task in a hot environment. *Appl Physiol Nutr Metab* 2014, 39:1159–1166.
135. Walker A, Rattray B, Brearley M. Perception or reality; can thermal perceptions inform management of firefighters in the heat? *J Occup Environ Hyg* 2017, 14:306–312.
136. Brearley M. Crushed ice ingestion – a practical strategy for lowering core temperature. *J Mil Veterans Health* 2012, 20:25–30.
137. Brearley M. Cooling methods to prevent heat related illness in the workplace. *Workplace Health Saf* 2016, 64:80.
138. Yeargin SW, Casa DJ, McClung JM, Knight JC, Healey JC, Goss PJ, Harvard WR, Hipp GR. Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength Cond Res* 2006, 20:383–389.
139. Smith KR, Woodward A, Campbell-Lendrum D, Chadee DD, Honda Y, Liu Q, Olwoch JM, Revich B, Sauerborn R. Human health: impacts, adaptation, and co-benefits. In: Confalonieri U, Haines A, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge/New York: Cambridge University Press; 2014, 709–754.
140. Hanna E, Bell E, King D, Woodruff R. Climate change and Australian agriculture: a review of the threats facing rural communities and the health policy landscape. *Asia Pac J Public Health* 2011, 23:105S–118S.
141. Hanna E, Tait P. Limitations to thermoregulation and acclimatization challenge human adaptation to global warming. *Int J Environ Res Public Health* 2015, 12:8034–8074.
142. Singh S, Hanna EG, Kjellstrom T. Working in Australia's heat: health promotion concerns for health and productivity. *Health Promot Int* 2013, 30:239–250.
143. Jia AY, Loosemore M, Gilbert D, Rowlinson S. Sheilding workers from heat stress: reconciling the paradoxes of protection and production logics. In: *32nd Annual ARCOM Conference*. Manchester:

Association of Researchers in Construction Management; 2016.

144. Scalley BD, Spicer T, Jian L, Xiao J, Nairn J, Robertson A, Weeramanthri T. Responding to heatwave intensity: excess heat factor is a superior predictor of health service utilisation and a trigger for heatwave plans. *Aust N Z J Public Health* 2015, 39:582–587.
145. O'Brien C. Griffith Taylor's climographs and contemporary blind spots. *Learn Commun Objects Govern* 2015, 15:26–31.
146. Department of Chief Minister. *Discussion Draft: Northern Territory Economic Development Strategy* Darwin: Northern Territory Government; 2015.
147. UNDP. *Climate Change and Labour: Impacts of Heat in the Workplace*. New York; UNDP; 2016.
148. Australian Bureau of Statistics. *2011 Census of Population and Housing*. Canberra: Australian Bureau of Statistics; 2012.
149. Dale A. *Governance Challenges for Northern Australia*. Future of Northern Australia Discussion Papers Series. Cairns: The Cairns Institute, James Cook University; 2013, 36.
150. Kirmayer LJ. Cultural competence and evidence-based practice in mental health: epistemic communities and the politics of pluralism. *Soc Sci Med* 2012, 75:249–256.
151. Noar SM, Harrington NG. *eHealth Applications: Promising Strategies for Behavior Change*. New York; Routledge; 2012.
152. McDonald H. East Kimberley concepts of health and illness: a contribution to intercultural health programs in Northern Australia. *Aust Aboriginal Stud* 2006, 2:86–97.
153. Christie M, Verran H. Digital lives in postcolonial Aboriginal Australia. *J Mater Cult* 2013, 18:299–317.

