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Understanding extreme heat and air quality impacts on vulnerable people in the Top End



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June 2022



About

This report was developed by the Menzies Institute for Medical Research, University of Tasmania, in collaboration with CSIRO and as part of the work of the Darwin Living Lab. The Darwin Living Lab was established to foster improvements in the liveability, sustainability and resilience of the city. The Darwin Living Lab is an initiative under the Darwin City Deal and is a 10-year collaboration between CSIRO and the partners of the Darwin City Deal: Australian Government, Northern Territory Government and the City of Darwin. The City Deal was signed by the Prime Minister of Australia, Chief Minister of the Northern Territory and Lord Mayor of the City of Darwin in November 2018.

More information and contacts available at: <https://research.csiro.au/darwinlivinglab/>

Acknowledgements

We acknowledge the Traditional Owners of the greater Darwin region, the Larrakia people, and recognise their culture, history and connection to this land and water. We pay our respects to their Elders past, present and emerging.

We thank the 23 participants who generously took part in the focus groups.

Ethics

This research was conducted within an ethics proposal approved by the University of Tasmania Human Research Ethics Committee (27058) with reciprocal approval from the CSIRO Human Research Ethics Committee (053/22).

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Citation

Campbell SL, Anderson CA, Wheeler AJ and Johnston FH (2022) Understanding extreme heat and air quality impacts on vulnerable people in the Top End. Editors: Muster TH and Cook S. Darwin Living Lab, CSIRO, Australia.

Cover Photo: Outdoor workers at CDU Education Precinct during construction, CSIRO 2022.

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Executive summary

This report outlines the research methodology and findings of how vulnerable individuals in the Darwin region of the Northern Territory (NT), Australia, perceive and manage episodes of extreme heat and poor air quality. This research was funded by the CSIRO-led Darwin Living Lab project.

A focus group methodology was used to gain greater understanding of heat and poor air quality issues. Three focus groups were conducted with identified vulnerable individuals: outdoor workers, teachers and carers and sports people.

Seven key themes emerged from the analysis of focus group discussions. These were (a) increasing temperatures, (b) impacts on work from heat and smoke, (c) impacts on health from heat and smoke (c) impacts on activity from heat and smoke, (d) adaptive behaviours, (e) lack of policy, and (f) doing the same things as usual.

These findings identified and highlighted gaps in education, infrastructure and policy that could improve the lives and protect the health of vulnerable people living, working and playing in the “Top End”. Key recommendations include (a) development of education packages and resources that cover the health impacts of heat and smoke, and adaptation strategies suitable for the location, (b) provision of grants for infrastructure improvement, (c) policy clarification and improvements to cater for the specific climate, and (d) future research to evaluate mitigation and adaptation strategies.

1 Introduction and Background

Anthropogenic climate change is recognised as having a substantive and negative impact on human health (Watts et al., 2015, Costello et al., 2009). While a changing climate will not necessarily impact health by way of introducing new diseases or disorders, it is likely to expand and amplify existing health risks (Blashki et al., 2011). One of the most significant of these includes the increased risk of mortality and morbidity as a result of increased intensity and severity of natural events and environmental hazards, including heatwaves, bushfires, floods, droughts, increased air pollution and increased pollen load (World Health Organization, 2012, IPCC, 2022). Furthermore, there is a disproportionate health impact from these types of events on Indigenous people, both locally and globally (Hanigan et al., 2008, Jones, 2019, Lansbury Hall and Crosby, 2022).

Heatwaves (also known as extreme heat events) pose a particular threat, having killed more people in Australia than all other natural disasters combined (Coates et al., 2014). Heatwaves discriminate to identified vulnerable populations such as the very old, the very young, outdoor workers and those with existing medical conditions (Bi et al., 2011). Research conducted globally and nationally demonstrate that heatwaves have a negative impact on mortality and morbidity (Campbell et al., 2018), and a major impact on health service delivery and capacity (Turner et al., 2013, Schaffer et al., 2012, Campbell et al., 2021). Overall, there are increasing negative health outcomes as temperatures increase (Gasparrini et al., 2015).

Smoke pollution and poor air quality from landscape fires is a globally significant public health problem (Johnston et al., 2012). The health impacts of poor air quality are known to be substantial, including increased mortality and morbidity, specifically for cardiovascular and respiratory outcomes (Johnston et al., 2007, Morgan et al., 2010, Borchers Arriagada et al., 2019). Research on the health impacts of the 2019-20 Australian 'Black Summer' fires estimated over 400 premature deaths, and over 2000 additional hospital admissions (Johnston et al., 2021).

1.1 Setting

Located in the far north of Australia's tropical region, Darwin has the highest average temperature and humidity of all Australian capital cities. Conditions are considered extreme enough to cause workforce shortages in critical sectors (Pendrey et al., 2021). Secondly, Darwin experiences severe smoke pollution every dry season, recording regular exceedances of the Australian air quality standard for 24-h average concentrations of particulate matter less than 2.5µm in diameter (PM_{2.5}) (de Jesus et al., 2020). A recently published study highlights the contribution of savannah burns in the NT on reductions in air quality (Jones et al., 2022). Darwin's savannah fire pollution, including that derived from prescribed burning, can be traced with very little confounding. With little traffic or industrial pollution, almost all (95%) of Darwin's particulate pollution is attributable to landscape fires (Denlay et al., 2001), and almost all early dry season fire is attributable to prescribed burning practices (Russell-Smith et al., 2020). Furthermore, at 25.5% of the population, the NT has the highest Indigenous population of all Australian states and territories by nearly ten-fold (Australian Bureau of Statistics, 2016).

Given these considerations, Darwin offers an ideal location to consider the problem of climate-related environmental hazard health impact on vulnerable populations. Local knowledge of the impact of these conditions is vital for both clinical surge capacity planning and public health promotion before and during these events, while understanding how these events impact vulnerable populations increases adaptive capacity of the community.

1.2 Policy drivers

A number of policy drivers exist supporting applied research on extreme heat risk in the NT. These include the *Northern Territory Climate Change Response: Towards 2050* document (Northern Territory Government, 2021b) and the *Darwin Heat Mitigation and Adaptation Strategy* (Northern Territory Government, 2021a). The heat mitigation strategy highlights the risk of extreme heat on vulnerable groups, including the elderly, the very young, those who lack mobility or who are unable to adequately care for themselves, those with limited resources to prepare or adapt, and those who are homeless. The strategy also highlights outdoor workers, schools and sports clubs as specific settings or groups worthy of adopting actions to adapt to extreme heat.

1.3 Project development

The original version of this project aimed to describe the range of symptoms perceived to be associated with extreme heat conditions in outdoor workers, and the frequency of symptom reports at differing meteorological thresholds. This was to be achieved by recruiting outdoor workers to use the AirRater app (University of Tasmania, 2022) over the build-up and wet season (October 2021-March 2022) and logging their heat-related symptoms while working outdoors. However, despite multiple attempts to recruit participants, including direct contact with 17 workplaces, a local newspaper advertisement, a webinar, blog posts and a radio interview, only 9 participants were recruited to the study. The study was therefore pivoted to a focus group approach.

1.4 Research aims

The aim of this project was to understand how individuals in the Darwin region perceive and manage episodes of extreme heat and poor air quality in the environment in which they live, work and play. A focus group methodology was employed to concentrate on the needs of specific vulnerable groups as identified by existing policy drivers (see Section 1.2). Three focus groups were identified: (i) outdoor workers (OW) (ii) teachers and carers (TC) and (iii) sports people who play and train in the build-up and wet season (SP).

2 Methods

2.1 Study recruitment

Participants for each focus group were recruited using purposive sampling: through social media, word-of-mouth and existing personal and professional networks. Recruitment was facilitated by a local organisation. Participants were gifted a \$50 shopping voucher to compensate for their time.

2.2 Data analysis

Focus group discussions were recorded. Data from the three focus group interviews was de-identified, transcribed and analysed with the Thomas (2006) data analysis framework. Using an inductive approach, data was sorted into themes and sub-themes common across all groups, that elucidated the core meaning of the data. A conceptual model based on the relevant themes and sub-themes was developed. NVivo 12 software (QSR International Pty Ltd, 2020) was used to assist with inductive thematic analysis.

3 Key findings

3.1 Characteristics of participants

Twenty-three participants took part in the research. Of those, 30% were males and 70% were female. As presented in Table 1, participants in each focus group tended to cluster by gender. There was a wide variation in the number of hours spent outdoors per week (3–40 hours), and the amount of time participants had lived in the Darwin/Top End region (7 months–64 years). Almost half the participants fell into the 25–34 year age group, with the remaining participants spread evenly across the age spectrum (Figure 1).

Table 1 Characteristics of participants

FOCUS GROUP	COUNT	GENDER (M/F)	HOURS SPENT OUTDOORS PER WEEK		YEARS LIVED IN TOP END	
			MEAN	RANGE	MEAN	RANGE
Outdoor workers (OW)	7	5/2	18.8	3-40	28.6	12-64
Teachers and carers (TC)	11	1/10	21.3	3-30	18.5	3-50
Sports people (SP)	5	1/4	13.4	7-25	12.4	0.6-29
TOTAL	23	7/16	17.8	3-40	13.2	0.6-64

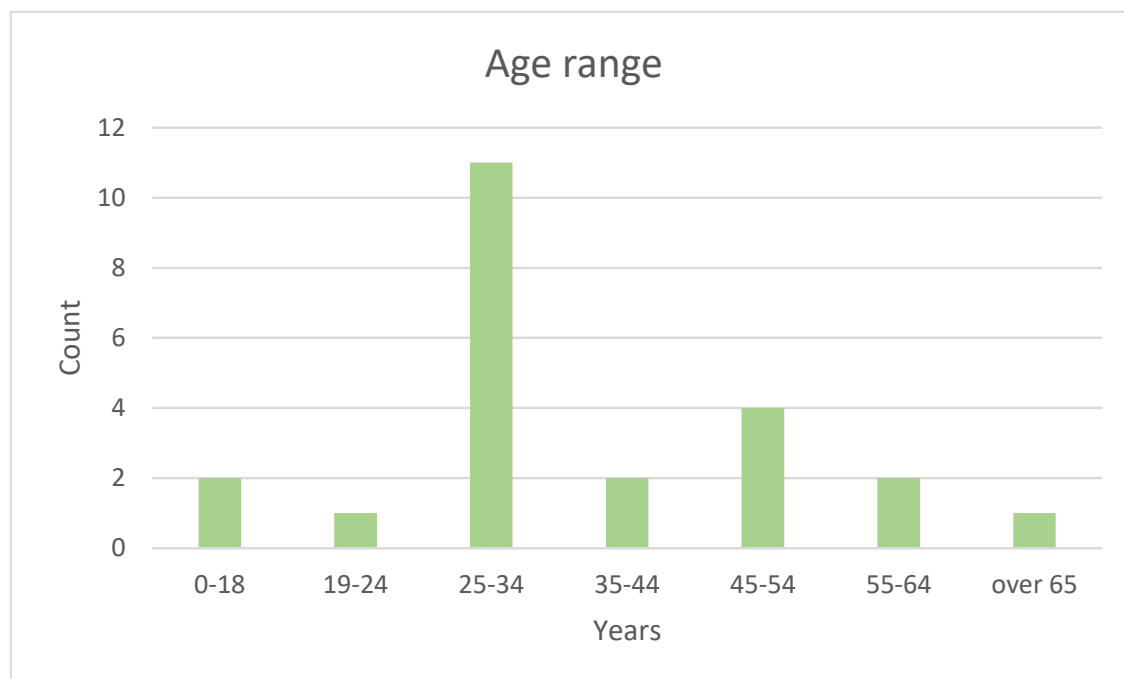


Figure 1 Age range of focus group participants

3.2 Focus group content analysis

Common themes across all focus groups were identified. These themes were:

- (1) increasing temperatures
- (2) impacts on work from heat and smoke
- (3) impacts on health from heat and smoke
- (4) impacts on activity from heat and smoke
- (5) adaptive behaviours
- (6) lack of policy and
- (7) doing the same things as usual.

There was a common perception among participants that it was getting hotter and that increased temperatures impacted on work, health and activity. Adaptation behaviours were used by participants because of hotter temperatures and decreased air quality from smoke. A lack of policy around increased temperatures and seasonal smoke created a barrier that resulted in work practices and sporting activities not adapting to environmental changes (i.e., doing the same things as usual), which ultimately had health and activity implications. Figure 2 shows the relationships between these themes.

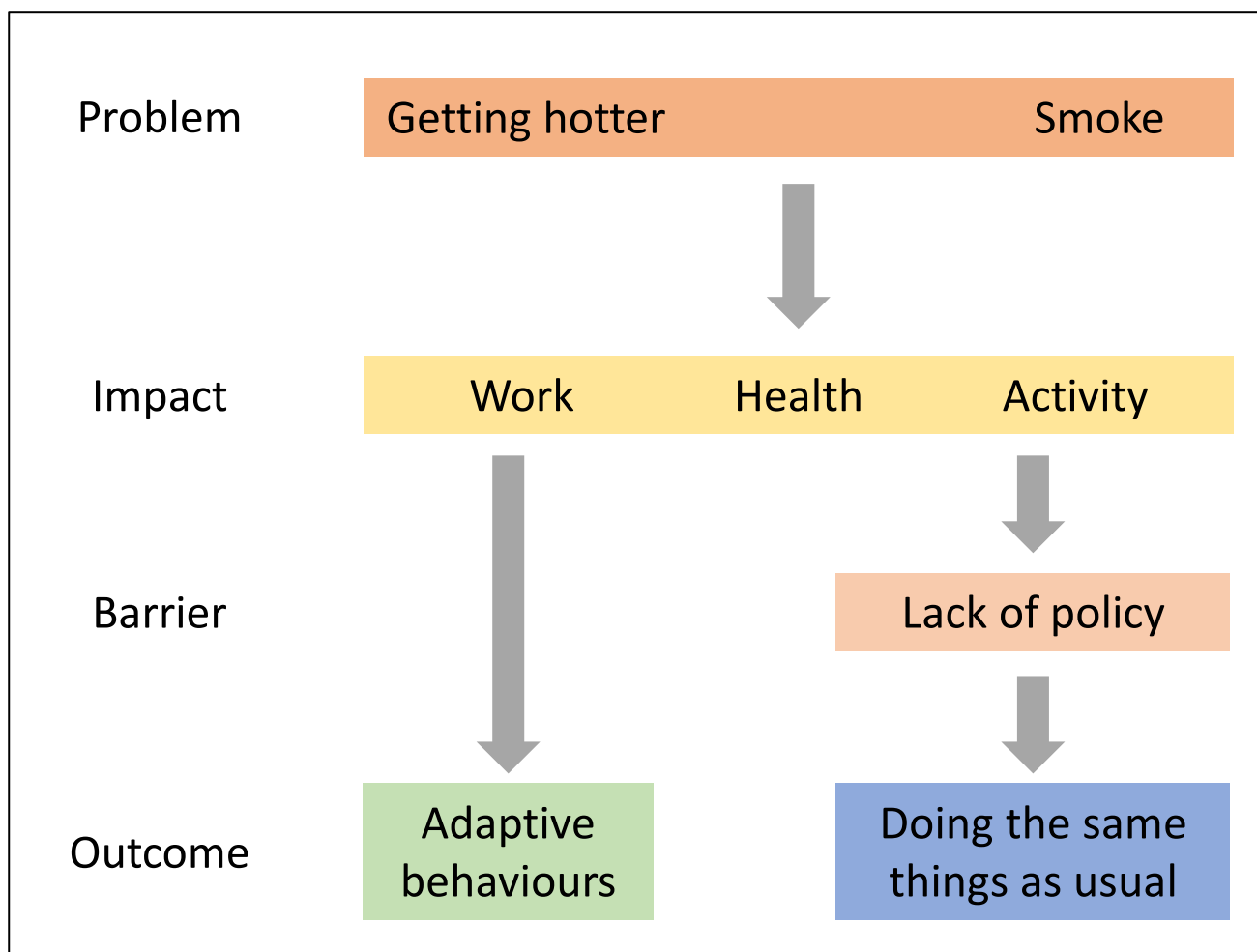


Figure 2 Interactions and relationships between key themes

3.2.1 Increasing temperatures

Across all focus groups, participants noticed that temperatures were increasing over time.

Even having been here 20 years, we've seen exactly the same thing. The temperatures are blatantly going up – OW

I think it's actually got hotter – SP

Record temperatures were also reported.

It broke the record for five days in a row – TC

3.2.2 Impacts on work from heat and smoke

Participants reported that heat impacted work productivity.

You get more done in the first three hours of work than the rest of the day – OW

I've had people who have lived in Darwin their whole life, first day on the job, they go down with heat stress. Yeah, it's a productivity thing as well ... but it's also if you're constantly being affected by heat stress – OW

Definitely as it gets hotter, yeah. I find myself making more mistakes – OW

Special considerations to activities in the workplace had to be made to prevent heat-related injuries. For example, teachers and carers reported how heat impacted infrastructure in the workplace.

Playgrounds with climbing frames that aren't under shade sails. Climbing frames get well over 40 degrees. Then grabbing on it burns on the hands – TC

And sandpit burns – TC

Smoke impacted work as it forced day-care centres to keep children inside. Consequently, teachers' workloads increased, as having children inside all day meant extra cleaning was needed.

So, if you've got to clean rooms or you've got kids coming out, so you've got to close down one yard and transfer children to another yard. It's like you're inside, the room is a mess and you've got to clean it all over again – TC

3.2.3 Impacts on health from heat and smoke

Heat and smoke had noticeable impacts on health. These impacts were both physical and psychological. Participants complained of heat and smoke induced health problems including, but not limited to, sore throats, respiratory complaints, visual problems, anxiety, dehydration, nausea, cramps and inability to concentrate.

You feel like passing out – OW

Tired. Lethargic. Can't be bothered. Irritable – TC

It's anxiety causing, very much so. So, stepping out into a smoky environment, it triggers something within me anyway, where oh my goodness if I'm not getting the air in and that just exacerbates other feelings and sensations – OW

Headaches were linked to dehydration:

Yeah, your head aches and you can't really satisfy your thirst for rehydration. I think that the more you try to rehydrate I think it almost feels like you can't do it, so you tend to not. So, there's kind of like a self-fulfilling prophecy for – and I see it all the time where people go way beyond it. Kids in sport...and I'm involved mainly in coaching...where they're way too thirsty to drink. That's a real problem – SP

Smoke was also linked to headaches.

Me, I find I get headaches, especially if there's a lot of tobacco or fire smoke around – OW

One outdoor worker explained how heat would affect cognition as well as fine motor skills:

It clouds your thinking as well, so when you get really hot, you're finding it hard to think straight, especially if you're dealing with anything that needs fine motor skills or coordination – OW

Smoke impacted respiratory health, especially for asthmatics. Smoke exacerbated asthma and caused asthma attacks.

I'm asthmatic. ... So, I'll be on the field and I'll start having symptoms before anyone else can smell the smoke. So, it impacts me significantly. And I had a real scare a few years ago where it was night-time burning off, so I could feel it happening. And I tried to get off, and my coach didn't sub me off. And then I got called back to a corner, as the runner. So, I tried to breathe out and I couldn't breathe. And I was running out from the corner. And I literally ran straight past the trapper, all the way off the field, into a full-blown asthma attack. And it was a really bad season for the fires up here, and we've got a few asthmatics in our hockey club. And I think three of us went down with asthma attacks on that round, on that day, and it was interesting the club's shift in it. So now the moment there is smoke or anything, straight away they ask us three, "Do you want to go on?" – SP

One outdoor worker reported that smoke can cause air filters in diving equipment to become blocked and compressed air to become contaminated. The combination of blocked air filters and contaminated air is potentially life threatening for commercial divers.

I used to be a commercial diver and whenever there was bushfires around on the harbour, especially if we were working later in the evenings...if you had the compressor on board, first you had to keep a real eye on what the weather was doing. As the air cools, the smoke drops. It only takes about five minutes before the filters are chockers, even just from a normal smoky day. Then getting contaminated air, it can be catastrophic – OW

3.2.4 Impacts on activity from heat and smoke

Separate from impacts on work productivity and health, participants identified the impacts on day-to-day activity from heat and smoke.

I do know that often if it is too smoky outside, we bring the children back inside, so they're not exposed to that smoke. Which reduces their outside time for play and running around – TC

Children get frustrated when they're inside all day – TC

It was perceived by participants that heat made physical activity more difficult, and was therefore less likely to be achieved.

I just find the air feels a lot thicker and heavier, so I find it harder to breath and work around that as well. And be motivated then to go out and go for a run, because it just seems that added layer in addition to running, having to breathe – SP

3.2.5 Adaptative behaviours

Participants highlighted that they adapted their behaviour because of heat and smoke. Behavioural adaptation strategies included, but were not limited to, cooling down behaviours, drinking more and modifying work and/or activity times.

Seeking shade was a common cooling down behaviour.

And also, if they're having a break, quickly try and have a shade break. In terms of my players, I'm so aware, if it's really hot, I'll modify sessions to help or have shorter, sharp bursts and then go in the shade – SP

When we stop and talk about something, it's predominantly in the shade, so we try and find a shady spot. We don't stand out in the sun and talk about things, it's just shade – OW

Ice baths and ice vests were also used to decrease body temperature in the heat:

Just put in the freezer. Yeah. Put it on, it's an ice vest – SP

I guess for our higher-level events, where they can be a bit more intense and a bit longer matches, we have inflatable baths that we set up as ice baths. For the players to – like under physio supervision, they'll use the ice baths throughout the tournaments. And then we also, during – if it gets to a certain temperature, where play is still allowed, but it is getting to the more extreme end, then they'll increase the break time between sets – SP

Increasing fluids and adding electrolytes was another adaptation behaviour used to mitigate the effects of heat.

Drink lots of water while you're working. I've had some days where I've drunk nine litres of water – OW

I just started putting electrolytes in my water bottle, not every day but probably three or four days a week. It depends on how long my shift's going to be – OW

Another adaptation behaviour was avoiding working during the hottest part of the day by adjusting work hours.

We started at two in the morning before, six, seven, just depends. Normally is eight – OW

To adapt to the smoky outdoor environment, closing windows and doors was seen as helpful. Once when doors and windows were shut, turning on air-conditioning helped to mitigate the heat.

When you're working outside, there's not much you can do about it. But if back at home, shutting all the doors and windows and turning the aircon on, you're going to have a bit of a decent sleep and escape it – OW

Teachers and carers described how they adapted by moving classes indoors to get away from the smoke.

I suppose it depends also how – the direction of the wind. And how far the fires are away. Because the wind always turns around and it might not – Then it blows it the other way. So, it's not as if you're constantly inside in the dry season because there's lots of fires around. It's very rarely where you go, "You know what? It's a bit too smoky out here. I think we should take them inside." So, just aware, I suppose – TC

3.2.6 Lack of policy

Although there was some evidence of existing policies to manage heat and smoke, there was an identified lack of policy specific to the conditions in the Top End, and space for improvements in policy overall. Lack of policies was identified as a barrier to adaptation.

I think they just put it in the too hard basket to do a policy specifically for more tropical climates. Compared to the policy for the southern climates. Because even across the NT, that would be different as well, even the Alice or the desert climate. And we're tropical up in Darwin. So, we'd need separate policies within the NT – SP

We've got nothing. When I say 'nothing', I'm actually not a [sport] NT or [sport] Australia [administrator], but the fact is that we play [sport] while we've got ash falling on us and heavy smoke, with three people being treated – SP

Inconsistency with policy was evidenced by this participant's comment about rules at different businesses.

It depends what centre – I've been at multiple centres and at some centres it's, "No, it's time for you to go outside." So, we're all going outside. Until whoever is in power comes outside and goes, "I don't want to be out here." And other centres where people don't want to go outside even if the day is quite nice. So, it does have that opposite effect in some centres as well – TC

Natural environments were identified to be more effective in cooling the environment, with a discussion around the ineffectiveness of using man-made products to cool the environment. Policy and funding support were considered as potential solutions to include more natural environments and help create cool places.

Especially outside, it has to be that natural environment. It has to be the trees, it has to be grass, it has to...like you were saying with the outdoor area with the water and the creeks and stuff like that. I think centres definitely need a lot more funding to go towards that outdoor environment, to keep it safe for the children. And to make it safe for the staff as well, to make it enjoyable to be outside and a lot cooler. Not sails, not Astroturf – TC

We should put it back to the government. So, something in the regulations through ACECQA [Australian Children's Education and Care Quality Authority] would be nice around the natural environment – TC

3.2.7 Doing the same things as usual

Without defined policies on heat and smoke, there was an expectation to do things the same way as had always been done, despite environmental changes in temperature and seasonal smoke. Local cultural influences were also mentioned.

*So there definitely is that sort of well, it's hot but you're in the Territory, so get on with it
– SP*

I think for the [sport], it's slowly changing but we touched on it before, I think the general attitude here is that it's been like this forever. We've done this forever. So, we kind of know that it's hot, but it's hot for everyone, so... we just get on with it – SP

Because the standard response is, "Oh, we've been doing it here for 70 years," so it doesn't actually...I don't think that stacks up – SP

Darwin does have - it is changing slowly, but it does have that 'we're territory tough' attitude. "Oh yeah, doesn't matter that it's 37 degrees, get out there and work." – OW

4 Policy implications and recommendations

Four key recommendations emerged from the findings. These involve (a) education, (b) provision of infrastructure, (c) policy improvements and (d) future research to evaluate mitigation and adaptation strategies.

4.1 Education

Participants were mostly knowledgeable regarding the impact of heat and smoke on their health, work productivity and activity. However adaptive behaviours differed markedly between groups and even within groups. Education programs that provide a greater understanding of the health risks associated with heat and smoke, and the inclusion of a broad range of adaptive skills and knowledge, would be beneficial to a wider community audience.

4.2 Provision of infrastructure

Participants commented on provision of shade and natural environments as key adaptation solutions. Seeding grants to provide this infrastructure are likely to increase this capacity. For example, grants for sport facilities to supply and maintain greater areas of shading for players, coaches and spectators would appear to be beneficial, as would grants for childcare centres to build and maintain natural shaded environments.

4.3 Policy improvements

Lack of or inconsistent policy was central to many focus group participants' concerns, and identified as a barrier to enabling more adaptive behaviours. Wide consultation with specific sectors would be beneficial in developing sustainable and enforceable policies to mitigate heat and smoke exposure, and reduce potential health harms.

4.4 Future research to evaluate mitigation and adaptation strategies

Areas for future research may include the development and testing of suitable alternative technologies (for example, workplace appropriate clothing, or personal heat and smoke monitoring devices). Research on the location and cost benefit of shading in common areas and facilities would also be of wide benefit.

5 Conclusion

This report provides the background, methodology, key findings, and future recommendations related to research conducted into the perceptions and adaptation strategies of vulnerable people in the Top End, in managing extreme heat and poor air quality. Focus groups represented known vulnerable populations and generated four key recommendations to address the challenges of heat and smoke exposure in this location.

Appendix A Focus group questions

The following questions were used to guide focus group discussions.

1. What is your personal understanding of how extreme heat can impact your health/the health of those you care for?
2. What about for poor air quality...what is your understanding of how this can impact your health?
3. Follow up question if not understood: For example, when there is a lot of smoke in the air?
4. How much of a problem is this for you/those you care for when you are working/playing/training?
5. When it's very hot, what sort of things can you do to manage the heat as you work/play sport outdoors?
6. What sort of things does your employer/sports club provide for you to manage in hot weather?
7. What about when its smoky? What sorts of things do you do to manage? And does your employer/sports club provide anything to help you?
8. What sort of things would you like to do that you haven't been able to? Is there anything that might help to make this easier for you? What do others do?
9. Do you think the culture of your workplace/sports club makes it easier or harder for you to manage extreme heat? For example, is it 'normal' to just 'get on with it'? Or are their strict rules around when you can work/play/train based on temperature or air quality?
10. Is there anything else you'd like to say about this topic?


References

- AUSTRALIAN BUREAU OF STATISTICS. 2016. *Census of Population and Housing - Counts of Aboriginal and Torres Strait Islander Australians* [Online]. Available: <https://www.abs.gov.au/statistics/people/aboriginal-and-torres-strait-islander-peoples/census-population-and-housing-counts-aboriginal-and-torres-strait-islander-australians/latest-release> [Accessed 9 June 2022].
- BI, P., WILLIAMS, S., LOUGHNAN, M., LLOYD, G., HANSEN, A., KJELLSTROM, T., DEAR, K. & SANIOTIS, A. 2011. The effects of extreme heat on human mortality and morbidity in Australia: Implications for public health. *Asia-Pacific Journal of Public Health*, 23.
- BLASHKI, G., ARMSTRONG, G., BERRY, H. L., WEAVER, H. J., HANNA, E. G., PENG BI, HARLEY, D. & SPICKETT, J. T. 2011. Preparing Health Services for Climate Change in Australia. *Asia-Pacific Journal of Public Health*, 23, 133S-143S.
- BORCHERS ARRIAGADA, N., HORSLEY, J. A., PALMER, A. J., MORGAN, G. G., THAM, R. & JOHNSTON, F. H. 2019. Association between fire smoke fine particulate matter and asthma-related outcomes: Systematic review and meta-analysis. *Environmental Research*, 179, 108777.
- CAMPBELL, S., REMENYI, T. A., WHITE, C. J. & JOHNSTON, F. H. 2018. Heatwave and health impact research: A global review. *Health & Place*, 53, 210-218.
- CAMPBELL, S. L., REMENYI, T., WILLIAMSON, G. J., ROLLINS, D., WHITE, C. J. & JOHNSTON, F. H. 2021. Ambulance dispatches and heatwaves in Tasmania, Australia: A case-crossover analysis. *Environmental Research*, 202, 111655.
- COATES, L., HAYNES, K., O'BRIEN, J., MCANENEY, J. & DIMER-DEOLIVEIRA, F. 2014. Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844-2010. *Environmental Science and Policy*, 42, 33-44.
- COSTELLO, A., ABBAS, M., ALLEN, A., BALL, S., BELL, S., BELLAMY, R., FRIEL, S., GROCE, N., JOHNSON, A., KETT, M., LEE, M., LEVY, C., MASLIN, M., MCCOY, D., MCGUIRE, B., MONTGOMERY, H., NAPIER, D., PAGEL, C., PATEL, J., DE OLIVEIRA, J. A. P., REDCLIFT, N., REES, H., ROGGER, D., SCOTT, J., STEPHENSON, J., TWIGG, J., WOLFF, J. & PATTERSON, C. 2009. Managing the health effects of climate change. *The Lancet*, 373, 1693-1733.
- DE JESUS, A. L., THOMPSON, H., KNIBBS, L. D., HANIGAN, I., DE TORRES, L., FISHER, G., BERKO, H. & MORAWSKA, L. 2020. Two decades of trends in urban particulate matter concentrations across Australia. *Environmental Research*, 190, 110021.
- DENLAY, J., COOK, G., GALBALLY, I., MEYER, M., CARUANA, A. & HUGHES, T. 2001. *Vegetation Burning Emissions in Darwin*. Darwin: NT Department of Infrastructure Planning and Environment,.
- GASPARRINI, A., GUO, Y., HASHIZUME, M., LAVIGNE, E., ZANOBBETTI, A., SCHWARTZ, J., TOBIAS, A., TONG, S., ROCKLÖV, J., FORSBERG, B., LEONE, M., DE SARIO, M., BELL, M. L., GUO, Y.-L. L., WU, C.-F., KAN, H., YI, S.-M., DE SOUSA ZANOTTI STAGLIORIO COELHO, M., SALDIVA, P. H. N., HONDA, Y., KIM, H. & ARMSTRONG, B. 2015. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, 386, 369-375.
- HANIGAN, I. C., JOHNSTON, F. H. & MORGAN, G. G. 2008. Vegetation fire smoke, indigenous status and cardio-respiratory hospital admissions in Darwin, Australia, 1996–2005: a time-series study. *Environmental Health*, 7, 42.
- IPCC 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate*

- Change. In: PÖRTNER, H.-O., ROBERTS, D. C., TIGNOR, M., POLOCZANSKA, E. S., MINTENBECK, K., ALEGRÍA, A., CRAIG, M., LANGSDORF, S., LÖSCHKE, S., MÖLLER, V., OKEM, A. & RAMA, B. (eds.).
- JOHNSTON, F. H., BAILIE, R. S., PILOTTO, L. S. & HANIGAN, I. C. 2007. Ambient biomass smoke and cardio-respiratory hospital admissions in Darwin, Australia. *BMC Public Health*, 7, 240.
- JOHNSTON, F. H., BORCHERS-ARRIAGADA, N., MORGAN, G. G., JALALUDIN, B., PALMER, A. J., WILLIAMSON, G. J. & BOWMAN, D. M. J. S. 2021. Unprecedented health costs of smoke-related PM2.5 from the 2019–20 Australian megafires. *Nature Sustainability*, 4, 42-47.
- JOHNSTON, F. H., HENDERSON, S. B., CHEN, Y., RANDERSON, J. T., MARLIER, M., DEFRIES, R. S., KINNEY, P., BOWMAN, D. M. J. S. & BRAUER, M. 2012. Estimated Global Mortality Attributable to Smoke from Landscape Fires. *Environmental Health Perspectives*, 120, 695-701.
- JONES, P. J., FURLAUD, J. M., WILLIAMSON, G. J., JOHNSTON, F. H. & BOWMAN, D. M. J. S. 2022. Smoke pollution must be part of the savanna fire management equation: A case study from Darwin, Australia. *Ambio*.
- JONES, R. 2019. Climate change and Indigenous Health Promotion. *Global Health Promotion*, 26, 73-81.
- LANSBURY HALL, N. & CROSBY, L. 2022. Climate Change Impacts on Health in Remote Indigenous Communities in Australia. *International Journal of Environmental Health Research*, 32, 487-502.
- MORGAN, G., SHEPPEARD, V., KHALAJ, B., AYYAR, A., LINCOLN, D., JALALUDIN, B., BEARD, J., CORBETT, S. & LUMLEY, T. 2010. Effects of Bushfire Smoke on Daily Mortality and Hospital Admissions in Sydney, Australia. *Epidemiology*, 21, 47-55.
- NORTHERN TERRITORY GOVERNMENT 2021a. Feeling Cooler in Darwin.
- NORTHERN TERRITORY GOVERNMENT 2021b. Northern Territory Climate Change Response: Towards 2050.
- PENDREY, C. G., QUILTY, S., GRUEN, R. L., WEERAMANTHRI, T. & LUCAS, R. M. 2021. Is climate change exacerbating health-care workforce shortages for underserved populations? *The Lancet Planetary Health*, 5, e183-e184.
- QSR INTERNATIONAL PTY LTD 2020. NVivo v12.
- RUSSELL-SMITH, J., EDWARDS, A. C., SANGHA, K. K., YATES, C. P. & GARDENER, M. R. 2020. Challenges for prescribed fire management in Australia's fire-prone rangelands – the example of the Northern Territory. *International Journal of Wildland Fire*, 29, 339-353.
- SCHAFFER, A., MUSCATELLO, D., BROOME, R., CORBETT, S. & SMITH, W. 2012. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis. *Environmental Health*, 11.
- THOMAS, D. 2006. A general inductive approach for analyzing qualitative evaluation data. *The American Journal of Evaluation*, 27, 237-246.
- TURNER, L. R., CONNELL, D. & TONG, S. 2013. The effect of heat waves on ambulance attendances in Brisbane, Australia. *Prehospital & Disaster Medicine*, 28, 482-487.
- UNIVERSITY OF TASMANIA. 2022. *AirRater* [Online]. Available: www.airrater.org [Accessed 12 June 2022].
- WATTS, N., ADGER, W. N., AGNOLUCCI, P., BLACKSTOCK, J., BYASS, P., CAI, W., CHAYTOR, S., COLBOURN, T., COLLINS, M., COOPER, A., COX, P. M., DEPLEDGE, J., DRUMMOND, P., EKINS, P., GALAZ, V., GRACE, D., GRAHAM, H., GRUBB, M., HAINES, A., HAMILTON, I., HUNTER, A., JIANG, X., LI, M., KELMAN, I., LIANG, L., LOTT, M., LOWE, R., LUO, Y., MACE, G., MASLIN, M., NILSSON, M., ORESZCZYN, T., PYE, S., QUINN, T., SVENSDOTTER, M., VENEVSKY, S., WARNER, K., XU, B., YANG, J., YIN, Y., YU, C., ZHANG, Q., GONG, P.,

MONTGOMERY, H. & COSTELLO, A. 2015. Health and climate change: policy responses to protect public health. *The Lancet*, 386, 1861-1914.

WORLD HEALTH ORGANIZATION 2012. Atlas of Health and Climate Change. Switzerland: World Health Organization.



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