Supplementary Submission No 35a

INQUIRY INTO HEALTH IMPACTS OF EXPOSURE TO POOR LEVELS OF AIR QUALITY RESULTING FROM BUSHFIRES AND DROUGHT

Organisation: Associate Professor Fay Johnston, Environmental Health Group, Menzies Institute for Medical Research, University of Tasmania

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IN THE MATTER OF
THE ROYAL COMMISSION INTO NATIONAL
NATURAL DISASTER ARRANGEMENTS

Witness Statement

Statement of:	**Dr Fay Johnston**
Occupation:	Associate Professor and Head of Environmental Health Research Group at the Menzies Institute for Medical Research, University of Tasmania Senior Medical Specialist, Public Health Services, Department of Health, Tasmania
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Date:	23 May 2020

I, Dr Fay Johnston, Associate Professor and Senior Medical Specialist, say as follows:

1 I was requested by the Solicitors the Inquiry to prepare a statement in response to several questions relating to health impacts and management of bushfire smoke in Australia. My responses to the questions put to me are set out below.

Describe (in summary terms) your key qualifications, professional experience and academic research in respect of the human health impacts of smoke, and the provision of public health advice in relation to the human health impacts of smoke.

Key Qualifications

Year	Qualification
2008	Doctor of Philosophy in environmental epidemiology (health effects of bushfire smoke), Menzies School of Health Research, Institute of Advanced Studies, Charles Darwin University.
1999	Fellowship of the Australasian Faculty of Public Health Medicine, Royal Australasian College of Physicians
1998	Fellowship of the Australian College of Rural and Remote Medicine
1997	Master of Applied Epidemiology. National Centre for Epidemiology and Population Health, Australian National University
1992	Diploma in Anaesthesia, Royal College of Anaesthetists (UK)
1990	Diploma in Obstetrics, Royal Australian College of Obstetricians and Gynaecologists
1987	Bachelor of Medicine and Surgery, Flinders University of South Australia

Experience

2 I am a public health physician and environmental epidemiologist with over 30 years of experience in practice, policy development and research. My current positions are:

(a) Associate Professor and head of the Environmental Health Research group at the Menzies Institute for Medical Research, University of Tasmania

(b) Senior Medical Specialist, Public Health Services, Department of Health, Tasmania

3 I worked in general practice and rural health in South Australia and the Northern Territory before completing a PhD in the health effects of bushfire smoke in 2008. I have since had a dual career in public health and research working in the government and academic sectors. My research program focusses on environmental determinants of health, particularly but not solely bushfire smoke, and the implications for Australian and international public health policy and clinical practice. I am a chief investigator with the NHMRC Centre for Air Pollution, Energy and Health Research - a nationally funded Centre of Research Excellence with a major stream of research focusing on bushfire smoke and related exposures.

4 I make frequent expert contributions to international scientific reviews of the health impacts of landscape fire smoke, and to state, national and international guidelines for managing landscape fire smoke episodes. As examples:

(a) I was part of an international expert group funded by Health Canada, to establish updated and evidence based guidance for the public health management of wildfire smoke(1);

(b) I was part of an expert group established by the Environmental Health Branch of the NSW Ministry of Health, to advise on their ongoing public health responses to smoke from a peat fire near Port Macquarie in 2019 and later the more extensive bushfire smoke episodes throughout NSW;

(c) I have contributed to the draft guidelines for public health responses to bushfire smoke, that are in preparation with the Environmental Health Standing Committee of the Australian Health Protection Principle Committee; and

(d) I made major contributions to the public health advice for bushfire smoke currently provided by Public Health Services, for the State of Tasmania.

(e) I have provided expert testimony to various inquires and legal proceedings relating to the community health impacts of smoke from the Hazelwood coal mine fire.

Research

5 I have made major research contributions to the understanding the health impacts of smoke from bushfires, savanna fires, coal and peat fires, and planned burns, which I collectively term landscape fires.(2)-(7) In particular, I have led many epidemiological research programs investigating short-term and long-term health impacts of exposure to smoke from landscape fires. I work closely with collaborators from many disciplines relating to the environment, air quality,

atmospheric science, fire sciences and health, and with partners in land and fire management agencies. Over the last 15 years I have received funding for research into the health impacts of smoke from State/Territory environmental agencies in the Northern Territory, New South Wales, Victoria, Western Australia and Tasmania, in addition to State Health Departments in Victoria and Tasmania, the British Columbia Center for Disease Control (Canada), the Bushfire and Natural Hazards CRC, the NHMRC and the Australian Research Council. Much of this research has been highly applied, focusing on decision-making, trade-offs and the efficacy of public health interventions.

6 Together with members of my team and my collaborators, my specific research contributions in this area have included:

(a) Characterising the global mortality impacts from all landscape fire activity and tropical deforestation fires[(8)]

(b) Demonstrating that serious exacerbations of asthma from landscape fire smoke occur at particle concentrations well below current national standards[(9)]

(c) Identifying lasting health impacts in young children and unborn babies exposed to up to six weeks of smoke pollution from a coal mine fire[(10)-(13)]

(d) Identifying a link between fire smoke exposure during pregnancy and the incidence of gestational diabetes[(5)]

(e) Demonstrating that interventions to reduce the number of wood heaters and improve outdoor air quality in the city of Launceston were associated with reduced mortality[(14)]

7 Much of my current research has focussed on interventions to reduce the health risks of smoke. My main contributions and ongoing work in this area include:

(a) Leading the team that developed AirRater (https://airrater.org/), an air quality, pollen and clinical surveillance system and smartphone app designed to support the health of people sensitive to poor air quality, especially those with lung conditions. It has provided data for understanding local drivers of respiratory symptoms among higher risk individuals.[(15)(16)] It was downloaded more than 50,000 times during the bushfire and smoke crises of 2019-20, especially in States and Territories where real time air quality information was not otherwise readily available to members of the public.

The AirRater team is based at the University of Tasmania. Team members are myself (epidemiology and public health), Dr Grant Williamson (data and analytics), Dr Chris Lucani (app development), Dr Amanda Wheeler (air quality), Dr Penelope Jones (pollen scientist, ecologist and manger), Ms Sharon Campbell (communication and evaluation), and Prof David Bowman (fire ecology). Our collaborators include air quality scientists from the CSIRO and the Environment Protection Authority (EPA) Tasmania, and the Tasmanian Department of Health.

(b) Understanding health trade-offs between planned burning and bushfires. With collaborators I have characterised the smoke related health burden from bushfires and prescribed burns in a range of settings in Australia and I have worked with fire ecologists who are characterising the benefits of prescribed burning programs.[(6) (17)-(28)]

(c) Evaluating cleaner air shelters. I have commenced a series of studies in a range of settings in Australia with high concentrations of outdoor smoke, to evaluate the utility of portable air filters in domestic and public buildings, as a means of health protection during events such as severe bushfire smoke episodes.

Describe your assessment of the human health risks associated with bushfire smoke, including by way of identifying (in general terms) particularly hazardous components of smoke.

8 Bushfire smoke is produced by the incomplete combustion of organic material, including plants and organic soils. It contains hundreds of different chemical species, which vary with the type of combustion (flaming/smouldering), transport and deposition, ongoing chemical reactions through time, and other factors. Constituents of smoke can be grouped into gases, such as carbon dioxide, and suspended particulate matter (PM), also known as aerosols. PM comprises a range of chemical species, including organic and elemental carbon compounds and is the most important constituent of smoke with respect to health impacts. Suspended particles range in size from visible soot to tiny nanoparticles. In general, the smaller the particles the greater their potential for causing harm to health. PM is the most important constituent of smoke and is strongly and clearly associated with a wide range of health impacts. For this reason, most smoke-related health research and public health advice focuses on PM. However, many other common constituents of landscape fire smoke also have adverse health effects. See Table 1 (below) for a summary.[(2)(29)-(35)]

Table 1. Major constituents and health impacts of smoke from biomass combustion[(2)(29)-(35)]

Constituent	Health impacts
Particulate matter (PM)	
	PM primarily comprises organic and elemental carbon components along with smaller contributions from inorganic species. PM is associated with a wide range of adverse health outcomes including mortality, exacerbations of respiratory and cardiovascular conditions, and pathophysiological changes such as inflammation, oxidative stress, and pro-coagulation.
Inorganic acids	
Carbon monoxide (CO)	Carbon monoxide is produced through incomplete combustion of biomass fuels. Human exposure to CO reduces the capacity of red blood cells to transport oxygen and therefore mainly affects the most oxygen sensitive organs: the brain and the heart.
Ozone	Ozone is formed photo-chemically near the top of smoke plumes in sunlight conditions. Ozone is associated with exacerbations of respiratory diseases.
Nitrogen and sulphur-based compounds	Both nitrogen and sulphur-based compounds are produced in proportion to their content in the burning substrate and the combustion efficiency of the fire. Smouldering combustion tends to produce reduced nitrogen compounds such as ammonia (NH_3), whereas flaming combustion produces oxides of nitrogen. Both these compounds are respiratory irritants.
Hydrocarbons	
Examples: benzo(a)pyrene benzene	Produced by incomplete combustion. These may be saturated, unsaturated, monoaromatic, or polycyclic aromatics. Some, such as benzo[a]pyrene, are mutagenic and carcinogenic. Butadiene, an unsaturated hydrocarbon is an irritant and neurotoxic. This group includes semi-volatile and volatile organic compounds such as benzene, naphthalene, and toluene. They are respiratory tract irritants. Benzene and naphthalene are classified as carcinogens.
Oxygenated organic molecules	

Constituent	Health impacts
Aldehydes	Some aldehydes such as acrolein are extremely irritating to mucous membranes of the human body. Others, such as formaldehyde, are carcinogenic. Some reduce the ability of scavenger cells in the lungs to engulf foreign bacteria.
Organic alcohols and acids	These include methanol and acetic acid, which are irritants and are teratogenic.
Phenols	Examples include catechol and cresol. These are known to be irritants, mutagenic, carcinogenic, and teratogenic.
Quinones	Quinones such as hydroxyquinone are irritants, allergenic, cause oxidative stress and inflammation, and are possibly carcinogenic.
Free radicals	
	Free radicals, such as semiquinones, are abundantly produced but most undergo condensation within a few seconds. Some may persist for up to 20 minutes and some may remain in organic material. They cause oxidative stress, inflammation, and are possibly carcinogenic.

Describe your assessment of the human health risks associated with bushfire smoke, including by way of identifying (in general terms) the range of potential and/or expected physiological responses on the part of relevant communities.

9 This summary focuses on the range of physiological responses to suspended PM generated by bushfires, specifically suspended particles with a diameter of less than 2.5 micrometres ($PM_{2.5}$). This focus reflects the concentration of research effort on the impacts of $PM_{2.5}$ – it does not reflect the complexity of smoke toxicology. However, there is currently insufficient evidence to characterise the potential additional role of other co-pollutants in smoke in contributing to the health impacts measurable at a population level.

Pathophysiology

10 Airborne PM, regardless of its source, drives a range of immediate physiological responses, such as the promotion of respiratory system and generalised inflammation, promotion of blood coagulation, increased production of toxic reactive oxidative chemical species, reduced blood vessel function and reduced autonomic nervous system reactivity. Many of these responses have been described specifically for PM from landscape fire smoke, although the smoke-specific evidence base is much smaller than for PM derived from other sources such as industrial or vehicular emissions.[(36)]

11 These core physiological responses can cause or exacerbate a wide range of health problems, including, but not limited to, respiratory conditions. Many respiratory conditions, especially asthma, worsen with increasing concentrations of smoke-derived PM even at relatively low concentrations.[(9)-(15)] For example, in an Australian cohort study of people with asthma, the commencement of oral steroids, (a 'rescue medication' for severe asthma) doubled with each 10 $\mu g/m^3$ increase in $PM_{2.5}$ derived from bushfire smoke, even in a setting where air quality standards were not exceeded.[(11)] These respiratory impacts are often felt rapidly and are due to PM-induced inflammatory and other immunological changes in the lungs.

12 Non-respiratory PM-induced responses throughout the body are more subtle and generally do not cause immediate symptoms. These include the promotion of immune responses, promotion

of coagulation of the blood, changes in the function of the heart electrical systems and blood vessel responses to stress.(36) However, in a person already at high risk, the small physiological changes induced by breathing smoky air can precipitate a serious event such as cardiac arrest, heart attack or stroke. Such serious outcomes are rare, but when large populations get exposed to smoke, the number of vulnerable people exposed to smoke can be substantial, and the likelihood of a death or other serious outcome is therefore much higher.(3)(20)(37)

Epidemiology

13 Studies of the short-term health effects associated with exposure to PM from bushfire smoke demonstrate that the health effects are generally similar to that of PM from a wide range of other sources which have been extensively studied. Health impacts clearly associated with exposure to bushfire smoke include:

(a) the worsening of existing diseases especially those affecting the respiratory and cardiovascular systems;

(b) increasing need for health care attendances including admissions to hospital; and

(c) increasing mortality rates.(36)(38)

14 Studies of PM and asthma and other respiratory conditions have shown greater impacts associated with smoke-related PM than with background, multi-source PM such as emissions from industry and transport.(39)(40) This suggests that PM from bushfire smoke has greater toxicity for respiratory outcomes than PM from other sources. For non-respiratory health outcomes there is not enough evidence to demonstrate differences in toxicity between bushfire-related PM compared with other sources of PM.

15 The longer-term health impacts from time-limited exposure to landscape fire smoke (such as during a bushfire crisis) have rarely been studied. Most long-term follow up studies evaluate long-term, or ongoing exposure to PM such as that associated with living in urban environments. An exception is the long-term follow up population that were exposed to smoke from the Hazelwood coal mine fire for up to six weeks in Victoria in 2014 (https://hazelwoodhealthstudy.org.au/). In the US, a long-term study of primates exposed to smoke from a wildfire in 2007 is ongoing, and human cohort studies were established following severe smoke events from fires in 2017 and 2018 to track human health impacts over time. These studies will produce important new evidence in time.

16 While respiratory and cardiovascular health outcomes have been the most studied, it is becoming increasingly understood that exposure to $PM_{2.5}$ has a wider spectrum of health outcomes including adverse impacts on blood glucose control, mental health and neurological function.(38)(41)(42) There is also emerging evidence that exposure to sudden increases in air pollution as seen with landscape fire smoke events could affect the development of unborn babies and infants.(10)(38)(43)(44) However, studies are few, the measured size of impacts are small, and the clinical significance of these subtle changes is not understood.

Describe your assessment of the human health risks associated with bushfire smoke, including by way of identifying (in general terms) any issues arising from the duration and/or level of exposure.

17 Most air pollution research on PM exposure, whether relating to fire smoke or not, has found a simple linear relationship between short-term (day to day) fluctuations in the concentration of PM, and health outcomes such as death rates, admissions to hospital, presentations to general practitioners or sales of medication for respiratory problems.[(38)] That is, the higher the air pollution concentration, and the longer the duration of exposure, the greater the health impacts. In general, if concentrations double, the number of people with adverse health impacts can be expected to double as well. Similarly, if a pollution episode lasts for two days it is anticipated that health impacts will be twice that of a similar pollution episode lasting for just one day. There is no evidence for a safe lower threshold below which there are no adverse health outcomes.[(45)-(47)]

18 Limitations to the general statement above are as follows:

(a) For <u>long-term</u> (chronic, or ongoing) exposure (eg years rather than days) the relationship is not linear. There is clear evidence that even though health impacts are much greater with long-term exposure that with short-term exposure, the health impacts of long-term exposure plateau at higher concentrations of air pollution. [(45)-(47)]

(b) There are not enough studies of <u>short-term</u> (ie daily or acute) associations to know if health impacts from landscape fire smoke plateau at very high concentrations such as a daily average of $PM_{2.5}$ greater than 200 $\mu g/m^3$ (as was observed in many locations over the 2019-20 summer).

19 This means that the cumulative population level health impacts of many days of minor smoke exposure could equal, or possibly exceed, a few days of severe exposure. This can be illustrated by evaluation of population level smoke exposure from prescribed burns and severe bushfires in Western Australia, over a 15 year period, which demonstrated that over time the adverse health impacts and costs from both sources of smoke were equivalent to each other despite considerable year-to-year variation (Figure 1).[(17)]

20 With respect to the health impacts of prescribed burning, the cumulative exposure throughout the year is a major determinant of overall population health impacts. This means that proactively managing and minimising the impacts of smoke from all prescribed fires, no matter how small, can produce substantial public health benefits over time.

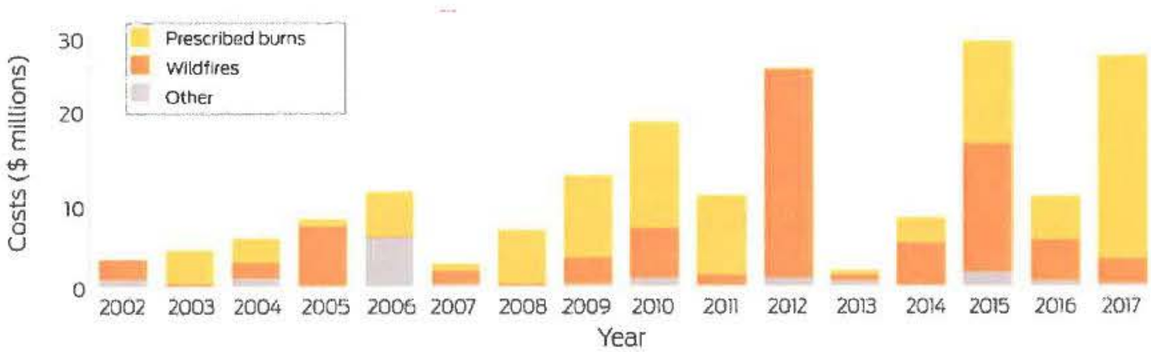

Figure 1. Estimated health costs attributable to elevated $PM_{2.5}$ concentrations, Western Australia, 2002–2017, by attributed source. (Adapted from Borchers et al 2020. [17] https://onlinelibrary.wiley.com/doi/pdf/10.5694/mja2.50547

Describe your assessment of the human health risks associated with bushfire smoke, including by way of identifying (in general terms) any issues arising from the geographic distance from the burning.

21 The transport and accumulation of smoke pollutants in the atmosphere is not my area of expertise. In general, people close to a fire front will be exposed to greater concentrations of air pollutants in smoke than people further from a fire. However, many factors other than distance also influence population level exposure to smoke. These factors include meteorological and topographical conditions that favour the accumulation or dispersal of smoke at the ground level where people breathe it. Smoke can be transported for thousands of kilometres and affect populations far from the source fires. If the source fires are ongoing, smoke can accumulate to cause severe air pollution.[6] As smoke 'ages' it undergoes physical and chemical changes which can affect the size distribution of the PM in the smoke and other chemical factors that shape its toxicology.

22 In summary, the concentration of PM at the location of sensitive individuals and populations is the most important factor determining health impacts from landscape fire smoke, and it is not possible to predict this from the geographic distance from the burning alone.

Describe your assessment of the human health risks associated with bushfire smoke, including by way of identifying (in general terms) any particular vulnerable community members.

23 Most healthy adults and children that experience smoke-related symptoms will recover quickly (ie. within days) from occasional acute smoke exposures and will not suffer from long-term adverse consequences. However, there are some population groups for whom adverse health effects from exposure to smoke are more likely.[48] Considered collectively, a large proportion of the population are in a higher risk group for adverse health impacts from bushfire smoke.

24 The most vulnerable sub-groups in a community include:

(a) Individuals with respiratory conditions such as asthma and chronic obstructive pulmonary disease[38][39]

(b) Individuals with cardiovascular disease which include high blood pressure, coronary artery disease, congestive heart failure, cerebrovascular conditions and angina[36]

(c) Adults aged 65 years of age or older, as they tend to have pre-existing respiratory and cardiovascular diseases [49]

(d) Populations with social and economic disadvantage[50][51]

(e) Aboriginal Australians possibly related to the greater burden of cardio-respiratory diseases, socioeconomic disadvantage and reduced access to health care among this sub-group[52][53]

(f) Younger children whose developing lungs make them more susceptible to the effects of air pollution. They tend to spend more time outdoors and they inhale more air per kilogram of body weight[54]

(g) Pregnant women and their developing foetuses[36][55]

(h) Individuals with chronic inflammatory conditions including diabetes[5]

(i) Women and men may have differential health risks with some studies finding women reporting more asthma-related symptoms or health visits than men[39]

Describe your assessment of the potential human health impacts of smoke associated with the 2019-2020 bushfires.

25 My team has estimated that in Queensland, NSW, ACT and Victoria combined, bushfire smoke from the 2019-20 fires was responsible for 417 excess deaths, 1124 hospital admissions for cardiovascular diseases, 2027 admissions for respiratory diseases and 1305 presentations to emergency departments for asthma.[56] Note that this rapid health impact assessment used estimates of population level exposure to smoke from the bushfires, and known relationships between deaths, admissions to hospital, and presentations to emergency departments for asthma. These estimates are not based on analysis of health data during the fires as such epidemiological studies take time.

26 Modelled health impact assessments are useful for providing rapid ballpark estimates but are subject to many assumptions and limitations. It is therefore very important that subsequent epidemiological studies are conducted to properly characterise the health impacts of this fire season, both short-term and long-term. As noted in the published paper, we did not attempt to estimate health effects for which exposure–response relationships are less well characterised, such as primary health care attendances, ambulance call outs or mental health impacts. See the publication from the Medical Journal of Australia (MJA) for full details.[56]

27 Figure 2 below is reproduced from a presentation I gave at the 3rd International Smoke Symposium, April 2020 (www.iawfonline.org/event/3rd-international-smoke-symposium/). It is based on work from my team evaluating smoke impacts and health costs associated with the same range of outcomes as described above, but also including Tasmania, South Australia and Western Australia in the analysis. A full paper describing this work is currently under review, and I can provide further details if requested.

28 The Figure illustrates our estimates of impacts by State and Territory from bushfire smoke since 2000. Health impacts of smoke pollution are not always included in economic assessments of the impacts of wildfires, which generally focus more on the costs of fire-related injuries, infrastructure losses and fire supression.[(57)-(60)] However, a few studies have estimated the health burden and/or associated costs of wildfire smoke exposure.[(61)-(67)] The figure shows the estimated annual health costs associated with bushfire smoke exposure for the most recent 20 fire seasons. These were derived from mortality costs, based on the value of a statistical life,[(68)] and the costs of hospital admissions for respiratory and cardiovascular diseases, and emergency apartment attendances based on the standard costs for each episode of health care.[(69)]

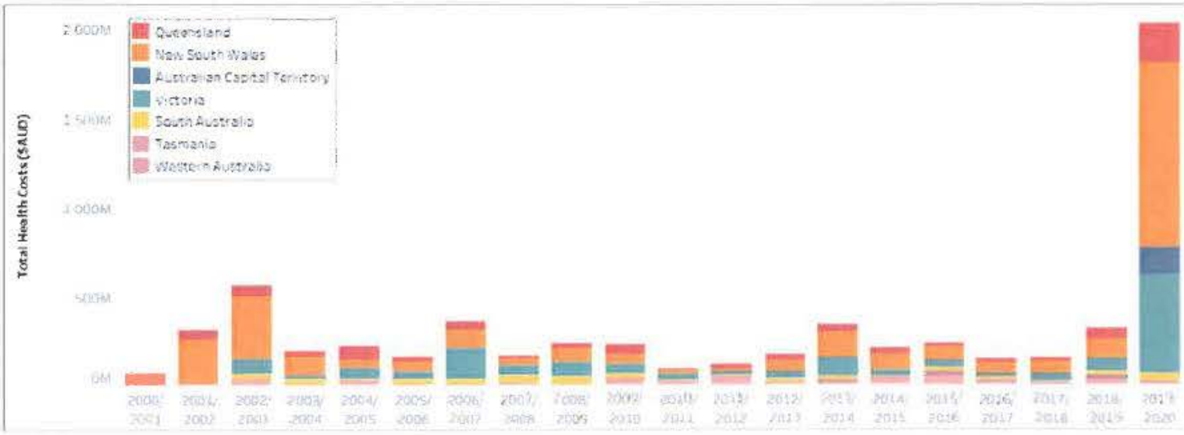

Figure 2. Annual fire season (1 Oct – 31 March) smoke-related health costs by state for 20 consecutive fire seasons since 2000 (paper under review). Air quality data was only available in the ACT and Tasmania from 2009.

29 We found that the 2019-20 season was a major anomaly in the recent record, with estimated smoke-related health costs of AUD$2.02 billion. These were largely driven by an estimated 445 smoke-related premature deaths in addition to 3340 hospital admissions for cardiovascular and respiratory disorders and 1373 emergency attendances for asthma. These estimates are slightly higher than those presented in the published paper in the MJA[(56)] because they are based on estimates made for seven rather than four States/Territories.

30 Health and economic impact assessments are subject to a range of assumptions and uncertainties. Those at greatest risk of death from short-term smoke exposure are likely to have pre-existing diseases[(36)] and potentially a shorter life expectancy than the average for others of the same age.[(70)] The valuation of the cost of these deaths was based on the value of a statistical life which is based on willingness to pay, and does not take into account underlying health status, age or life expectancy of the individual. While there is uncertainty about how these factors affect the value ascribed to the premature mortality component of the smoke-related health economic burden, it does not influence the relative difference in economic burden between years.

Describe any practical actions that you can identify to mitigate the matters identified.

31 I have divided my response to this into two sections as follows: (1) system level actions from Governments and other agencies and (2) individual actions. I note that much of the responsibility for monitoring air pollution and managing health risks associated with air pollution lies with health and environment agencies within each State and Territory (jurisdictions) of Australia.

System-level actions: Work to mitigate the climatic trends that are increasing the frequency of conditions favourable to severe bushfires

32 While not my direct area of research expertise, the evidence shows that global fire seasons are becoming longer with more extreme fire weather causing more intense and destructive fires.(71) This trend is likely to worsen according to climate projections.(72) More frequent and severe fires will lead to greater population exposure to severe bushfire related air pollution.(73) For example, while summer bushfires are an inherent feature of temperate, forested Australian environments, the fire season of 2019-20 was anomalous given the geographical scale of the fires burning over eight million ha (Figure 1),(74) driven by prolonged drought and dangerous fire weather(75) that has been attributed to anthropogenic climate forcing, with ignition from dry lightning and a variety of anthropogenic causes.(76)

System-level actions: Improve the evidence base for public health advice

33 The evidence base for much of the standard health advice provided by government agencies is poor and existing evidence is often not well incorporated into practice. There is very little available evidence about the risk of persist health impacts following severe smoke events, or comparative impacts of $PM_{2.5}$ from different types of combustion. Further, advice (eg to stay indoors) that is appropriate for brief episodes of pollution, such as a few hours of smoke from a planned burn, is not necessarily appropriate for prolonged and severe episodes such as that experienced over the 2019-20 summer. Evidence for the appropriateness of face masks for the general population is lacking,(77) while evidence to support indoor air filtration to protect health exists, there also gaps about how and where indoor air filtration is effective and this strategy is not routinely incorporated into agency health advice.(78)

System-level actions: Establish a comprehensive public education and communication strategy

34 Australians need to learn to live with bushfires, planned burns and the associated air pollution. These hazards are not avoidable and will increase in the future. Air pollution, fire, and smoke management all have strong influences on population health, yet are complicated to understand and respond to. The public will be better protected if better educated about issues such as: who is at risk? in what way are they at risk? what steps should be taken to reduce risks? what are the best ways to understand and manage fluctuations in air quality? how is air quality data best interpreted?

35 This campaign could be modelled on similar educational campaigns about other environmental hazards common in Australia such as managing the risks and benefits of exposure to UV radiation from the sun. Ideally it will be supported by and reflect nationally consistent health protection policy and practices (see below).

System-level actions: Create a national strategy for health protection from bushfires, air pollution and related environmental threats to population health

36 Traditional health protection activities by government (eg immunisation programs) were established prior to the current era of escalating risk from landscape fires, heatwaves and other environmental hazards. Expertise and experience in bushfires, smoke and public health is currently fragmented throughout Australia. Some lies within universities and some within government health agencies, some within government environment agencies, and some is outside all of these sectors. As described further below, this has led to some fragmented and inconsistent responses to air quality management and bushfire smoke emergencies across Australia. This is why, in recent article in the Medical Journal of Australia co-authored by myself with other leading experts in air pollution in Australia, we called for a national strategy incorporating expertise from a range of disciplines (Vardoulakis et al 2020).[48] The full paper is appended to this report.

System-level actions: Predict likely smoke impacts for populated areas where possible and share in accessible ways with the affected populations

37 Advance notification makes managing the smoke and health impacts considerably easier for people who are highly sensitive to smoke, such as those with asthma, and can avoid important impacts such as worsening symptoms or missed school or work.[79] To be effective, many actions for reducing smoke exposure need to be done in advance of severe smoke impacts. For example sealing a home or workplace by closing doors and windows is not effective if it is done after air quality has worsened.[80] Similarly, another effective intervention for people with asthma is to use preventive medication, but this is only possible if advance notice of possible worsening air quality is possible.[20][81]

System-level actions: Ensure real-time air quality information is available and easily accessible

38 Advanced warning of air quality impacts of smoke from uncontrolled bushfires is not always possible. However, the sharing of near real-time air quality information is possible in areas with air monitoring networks. The ability to access timely information is crucial for high risk individuals who can experience deterioration in their health with modest changes in air quality, well before 24-hour national air quality standards are exceeded.[9] Early notification of worsening air quality enables preventive action such as seeking cleaner air spaces, sealing an indoor environment, or taking preventive medication, all of which are far less effective if left until smoke impacts are obvious and severe.

39 While most jurisdictions have web-based information about the location of fires, the location of smoke is harder to access and it can be difficult or impossible, especially for individuals in some higher risk groups such as the elderly, to find and interpret air quality data relevant to their personal location.

System-level actions: Expand the air quality monitoring network

40 An additional issue to air quality data accessibility is data availability. As was highlighted over the 2019-20 bushfires, many areas of rural and regional Australia – and even some parts of urban

Australia – have no access to accurate air quality information because of the sparse nature of Australia's air quality monitoring network. Where gaps exist, increasing the network of air quality monitors across areas of Australia would have a clear benefit.

System-level actions: Increase the affordability and accessibility of high efficiency particle air (HEPA) filters especially to populations at higher risk of adverse health effects from bushfire smoke.

41 A practical strategy, with good evidence for reducing both the indoor smoke and health impacts, is the use an indoor HEPA filter.[78] However, most research has been done in overseas settings and more research needs to be done in Australia. As episodic smoke exposure is an inevitable part of living in Australian environments it would be logical to subsidise the costs of portable HEPA filters for people at higher risk of health impacts from air pollution from any source.

Individual actions

42 The key actions for an individual to protect themselves from the harmful effects of bushfire smoke fall into three broad groups.

(a) **Actively manage personal health**, especially any chronic medical conditions like asthma, heart disease or diabetes

(b) **Reduce the amount of smoke that you breathe.** Methods for doing this include staying indoors in a room well sealed from the outside air, ideally with an additional system for filtering particles from the air, and moving to less smoky environments (eg air-conditioned public buildings or less affected geographic areas), if practical.

(c) **Track the smoke** so appropriate action can be taken in a timely way, eg homes can be aired and exercise can be scheduled when it is not smoky, and protective actions can be taken as air quality worsens.

43 Box 1. (next page) which I have reproduced from the paper by Vardoulakis and colleagues,[48] lists benefits and limitations of a range of potential personal risk reduction measures for bushfire smoke events.

Box 1. Benefits and drawbacks of personal risk reduction measures during bushfire smoke events (from Vardoulakis et al[48])

3 Benefits and drawbacks of personal risk reduction measures during bushfire smoke events

Risk reduction measure	Benefits	Drawbacks
Staying indoors (at home, workplace or school)[17]	• Effective in reducing personal exposure to $PM_{2.5}$ in relative well sealed rooms with: ▸ air conditioning (on recirculating mode) ▸ air filtration (with HEPA filters) ▸ no indoor pollution sources (eg, cigarette smoking)[17]	• Building overheating and low air exchange rates resulting in high indoor temperatures and carbon dioxide levels* • Significant upfront cost for installation of air conditioning/filtration systems[5] • Ineffective over longer periods of time (ie, several days) without additional air filtration[5]
Reducing strenuous physical exercise outdoors[17]	• Effective in reducing personal exposure to bushfire smoke* • Limiting exertion in children may be especially important for reducing their exposure to particles[19]	• Could be detrimental to cardiovascular and mental health if air pollution persists over longer periods, unless other opportunities for exercising are provided (eg, indoor sports centres)[17]
Using a clean air facility or public building with good indoor air quality (eg, air conditioned shopping centre, public library, community centre, sports centre)*	• Effective in reducing exposure to outdoor air pollution over short periods (ie, hours)*	• Impractical over longer periods of time (ie, several hours)* • At-risk individuals may need onsite medical assistance or ambulance transport* • Large numbers of facilities will be required in cities* • Facilities may need retrofits for airtightness or installation of HEPA filters for air intake*
Portable air cleaners (air purifiers)[17]	• Effective in reducing indoor air pollution levels if fitted with HEPA filters[5–17] • Highly effective in well sealed rooms of certain size as recommended by manufacturer[5–17]	• Less effective in less airtight houses, which are common in Australia* • $PM_{2.5}$ removal rate dependent on flow rate of air cleaner[15] • Significant upfront purchase cost • Availability may be limited in areas heavily affected by bushfire smoke*
Face masks, including professional masks and surgical masks[20–22]	• Well-fitted professional (eg, P2/N95) masks offer effective protection from $PM_{2.5}$ exposure[21] • Professional masks are generally suitable for outdoor workers* • Exhalation valves can reduce build-up of humidity and carbon dioxide within masks*	• Difficult to achieve good facial fit with professional masks (eg, due to small face, facial hair, etc)[20] • No professional masks are made for children • Surgical masks offer only moderate protections[20] • Improvised cloth masks, bandanas or t-shirts offer no protection[20] • Face masks may give false sense of security[22] • Uncomfortable to wear over longer periods*
Antioxidant supplements, fish oils (omega-3 fatty acids), and other dietary advice[18,19]	• Suggestive evidence that carotenoids and vitamins D and E may protect against pollution damage which can trigger asthma, chronic obstructive pulmonary disease and lung cancer initiation[18] • Vitamin C, curcumin, choline and omega-3 fatty acids may also have a protective role[18,19] • A healthy diet, rich in fruits and vegetables, is generally beneficial (however, there is no direct evidence of protective effect of diet against air pollution)[18]	• Dietary supplements can provide long term and potentially short term health benefits but may be costly* • Supplements should not be used as substitute for a healthy and balanced diet* • More research is needed to prove effectiveness of supplementation in reducing health risks from air pollution exposure*
Asthma medication, aspirin, statins, other medications[17]	• Asthma preventive medication can attenuate exacerbations of the condition* • There is very little evidence that aspirin, statins or any other medication have direct protective effects against air pollution[17]	• Advance notice of smoke events is required to enable asthma preventive medication to be used*
Smoke forecasts, near-real time air quality data ($PM_{2.5}$), air pollution and health alerts[5]	• Mostly free to use and can enable individuals to develop personal smoke exposure reduction plans* • Localised hourly air quality information more useful than 24-hour rolling averages or spatially averaged data*	• Plethora of air quality websites, apps and indicators, which are not always well validated* • Information in electronic media may not reach some sensitive groups (eg, older people)*
Temporary relocation[16]	• Can provide health protection to at-risk groups, such as pregnant women, or people with serious lung or heart disease, affected by localised but persistent smoke episodes*	• Impractical when large population centres are affected* • Difficult and expensive to relocate many people* • Socio-economically deprived individuals, older people and those who are very ill have lower ability to relocate safely[16] • Cognitive impairment and restricted mobility could compound the stress of relocation[16]

HEPA = high efficiency particulate air. $PM_{2.5}$ = atmospheric particulate matter with a diameter < 2.5 μm. * Based on the authors' expert opinion.

In relation to the actions identified above, comment (to the extent you are aware) as to the extent to which such actions already form an active part of mitigation activities and whether and how those activities might be improved.

44 There is uptake of some of these actions in some jurisdictions and nationally. The list below is not comprehensive, and simply reflects what I know of.

System-level actions: Work to mitigate the climatic trends that are increasing the frequency of conditions favourable to severe bushfires

45 While some states and territories have climate action mitigation plans in place, there remains an urgent need for a comprehensive, coordinated and funded national strategy covering mitigation actions for all major sources of emissions. Evidence from other countries show that such plans are effective in reducing emissions.

System-level actions: Improve the evidence base for public health advice

46 Increased funding for research relating to the health impacts of bushfire smoke, and individual and population level interventions to reduce these impacts, is needed to improve the evidence base for public health advice. In January 2020 the National Health and Medical Research Council did make a special call with modest funding available specifically for research relating to health impacts of bushfires.

System-level actions: Establish a comprehensive public education and communication strategy

47 Not yet in place. This requires long-term support, funding and resourcing to be effective. Ideally this campaign is nationally consistent and fits with a national health protection strategy (see 48 below).

System-level actions: Create a national strategy for health protection from bushfires, air pollution and related environmental threats to population health

48 A national health protection strategy for landscape fire smoke and related hazards that are increasing as the climate changes will increase Australia's resilience in the face of environmental change. There have been calls for a national health protection strategy for other increasing threats to health including multi-jurisdictional hazards such as bushfires, air pollution events, respiratory epidemics including thunderstorm asthma, and novel infectious diseases.(48)(82)(83)

System-level actions: Predict likely smoke impacts for populated areas where possible and share in accessible ways with the affected populations

49 Some jurisdictions (eg NSW) conduct their own air quality forecasts, while the CSIRO and Bureau of Meteorology are developing the AQFx forecasting system. Further resources are needed to improve, validate and integrate forecasting systems into practice. An example of automated notifications of forecast for reduced air quality is that provided by the Department of Planning, Industry and Environment in NSW. The EPA Victoria display air quality forecasts for the following day on their web pages.

System-level actions: Ensure real-time air quality information is accurate and easily accessible

50 While all states operate websites with public air quality information, as noted in Q6 below, these vary greatly in the types of information displayed, including air quality categories, use of averaging periods and units.

51 AirRater (www.airrater.org), developed by our team at UTAS, is an example of an air quality communication system that uses a smartphone app to provide available data at the user's current location in as close to real time as available. The demand for such information for managing personal exposure to smoke was illustrated during the 2019-20 bushfire smoke crisis during which time it was downloaded in excess of 50,000 times throughout Australia as the only single source of hourly (or more frequent) $PM_{2.5}$ concentrations for all of Australia.(84) Evaluations of AirRater have demonstrated that it is used by people to manage their health, by supporting decisions about when to open or seal up a home, take medication or move to a less smoky environment.(16)

52 The establishment of a singular, reliable and trusted source of air quality information across Australia is vital to the success of 47 and 48 above. While options exist to provide this service (eg AirRater, which shares data from Government agencies, is currently funded in Tasmania, ACT and NT), there is currently no funding to operate this, or any other service nation-wide.

53 Many websites claim to provide real time air quality data. However, the quality and accuracy of the data shared is highly variable. It is often not made clear if the data are real-time or averaged over 24 hours, if international or Australian standards were used to generate an index, or if the data provided are modelled estimates, measured by validated monitors, or measured by unvalidated or uncalibrated low cost sensors.

System-level actions: Expand the air quality network

54 Several jurisdictions have used lower cost monitors and sensors to provide wide population coverage of PM monitoring. Tasmania has had a network of calibrated DustTrak monitors in place since 2009. Victoria and NSW have also considerably expanded the capacity using lower cost sensor networks and mobile stations.

55 Gaps in the national air quality network were apparent in many rural areas affected by bushfire smoke in 2019-20. While an air quality monitoring station in every town across Australia may be cost-prohibitive, further exploration of ways to fill these gaps, including evaluation of low-cost sensors is needed to address this gap.

System-level actions: Increase the affordability and accessibility of high efficiency particle air (HEPA) filters especially to populations at higher risk of adverse health effects from bushfire smoke.

56 An example of their use was during the Tasmanian bushfire crisis of 2019 when HEPA filters were established in all fire evacuation centres to provide a cleaner air shelter for people in vulnerable groups. Further research funding is needed to clarify the most appropriate ways to implement this intervention in Australia.

Individual actions

57 As with system-level activities, improving the implementation of individual-level mitigation activities is likely to require additional capacity, resources, research and funding, including but not limited to the broadscale public education campaign suggested above. Nearly all advice outlined above for individual actions in Q4 requires further research to characterise under what circumstances they will be most effective (eg during a severe bushfire event). This includes (1) staying indoors, (2) closing doors and windows, (3) changing exercise patterns, (4) using air filtration, (5) using a face mask, or (6) implementing nutritional or medical interventions. See Box 1 above for a summary of the benefits and limitations of some potential interventions.

58 Individual actions require a relatively high level of understanding of smoke and health, and what to do about it. This is why I believe that a comprehensive public education campaign is needed in Australia.

Describe the current method(s) and metric(s) used to measure air quality characteristics relevant to the human health impacts of smoke within relevant jurisdictions of Australia.

59 I have divided my response into two sections. One describes the main methods used in Australia, and the other describes the main metrics used.

Main methods used in Australia

60 I am not an expert on the technical methods used for measuring air pollutants. However I am familiar with the main methods used in Australia as I use data from these in my research and public health practice. In Table 2 below I have provided a summary of the main methods used to measure $PM_{2.5}$, the pollutant which is most important with respect to the human health impacts of bushfire smoke. For further technical detail and information, an technical expert in this area should be consulted.[(85)-(87)]

Table 2. Main methods used for measuring airborne concentrations of particulate matter.

Measurement method	Notes
Gravimetric measurement via a low volume air sampler with a filter. **Metric**: micrograms per cubic metre of air (µg/m3) as a (24h average)	This is the core reference method in Australia and globally. Filter is weighted before and after active sampling at a specified flow rate for a 24-hour period to determine 24 hr $PM_{2.5}$ amount.
Tapered Element Oscillating Microbalance (TEOM) or TEOM- Filter dynamic measurement system (FDMS) **Metric**: µg/m^3 (continuous)	A TEOM continually measures the concentration of airborne particles by collecting the particles on a filter located at the end of a thin quartz fibre which oscillates. The period of oscillation is dependent on the total mass of filter and particles. In Australia jurisdictions operate the TEOM with the filter controlled to 50 C. This leads to significant loss of volatile particles from the filter under some circumstances. A more modern version, the TEOM-FDMS incorporates a system that alternates between ambient air and filtered-air pathways. This, in principle, allows better estimation of volatile and non-volatile components than a standard TEOM, which is important for $PM_{2.5}$ measurements. Standard method under Air Quality NEPM
Beta Attenuating Monitoring (BAMs) **Metric**: µg/m^3 (continuous / close to continuous)	Uses the attenuation of beta radiation (electrons) by solid particles extracted from air flow to detect PM. BAMs are widely used across Australia. The first units provided hourly-averaged data, but more modern units can provide a 5-minute running average. Standard method under Air Quality NEPM
Optical particle counters (e.g. DustTraks) **Metric**: µg/m^3 (continuous/close to continuous)	Optical particle counters use scattered light to measure and count particles. Algorithms are used to convert particle counts to mass measurements (µg/m^3). Not a standard method under Air Quality NEPM but used by many jurisdictions to expand reach of air quality monitoring network as the sensors are lower cost. With appropriate calibration that the data quality is very high. These devices also can provide very high time-resolution data. Data quality is less reliable if a varying mix of aerosols of similar size (smoke, diesel exhaust, etc) are present in the ambient air.

Main metrics: Measured concentrations

61 The main metric used to describe smoke pollution is $PM_{2.5}$ in μg/m^3. Australia's national standard, and most public health guidance, is based on a measured average over a 24-hour period. All the methods described above are used for calculating the mass concentration of particulate matter per cubic metre of air.

62 Historically, air quality standards were not designed to support the management of episodic severe smoke from bushfires, but to assist in the regulation of sources of anthropogenic emissions air pollution (eg vehicle emissions), and to manage and monitor daily variation and longer-term air quality trends.

63 A 24-hour average of the concentration of pollution does not provide sufficient information about the large and rapid fluctuations in air quality that are often associated with smoke from bushfires.

Main metrics: Air Quality Indices

64 Many jurisdictions report an Air Quality Index (AQI) in preference to or in addition to concentration of $PM_{2.5}$ in ug/m^3. The AQI can be calculated and presented in several different ways. It is not used consistently throughout Australia or internationally.

65 The AQI was designed to standardise information across different types of air pollution. It can be used for any pollutant (including fine and coarse particulate matter, carbon monoxide and ozone) and can be calculated for pollutants either individually or collectively.

66 The index is not a raw measurement (e.g. micrograms of pollutant per cubic metre of air), but a scale based on how much the reading is above (or below) the air quality standard. Some States and Territories provide the AQI separately for different pollutants (e.g. an AQI for NO_2, and an AQI for $PM_{2.5}$), others provide only a composite AQI that is based on the worst measurement of all pollutants measured.

67 The AQI is scaled so that if a pollutant is measured at a concentration equal to the air quality standard set for a specific pollutant, the AQI will be reported as 100. As standards vary by country, an AQI is not an internationally uniform index. For example, an AQI for $PM_{2.5}$ of 100 in Australia represents a lower concentration of $PM_{2.5}$ than an AQI of 100 in the US.

68 In Australia, where our 24-hourly standard for $PM_{2.5}$ is 25 μg/m^3, the AQI for $PM_{2.5}$ can be calculated by multiplying the measured 24h average concentration of $PM_{2.5}$, (in μg/m^3), by four. This conversion factor does not apply to any other pollutant.

69 Importantly for $PM_{2.5}$ from bushfire smoke, the AQI is calculated from a 24-hour average. The rolling 24-hour average used to calculate the AQI means the AQI will change more slowly in response to changing conditions than the 1-hour or 10-minute averages that may potentially be presented for $PM_{2.5}$ if measured by a method that produces continuous measurements. Table 3 shows the metrics used for reporting $PM_{2.5}$ on the air quality data on the main air quality web page of the environment agencies in each jurisdiction.

Table 3. Main reporting metrics displayed for $PM_{2.5}$ by State and Territory

State/Territory	**Displays $PM_{2.5}$ as AQI**	**Displays the measured concentration of $PM_{2.5}$ ($\mu g/m^3$)**
ACT	AQI derived from all monitored pollutants including 24-hour average $PM_{2.5}$	Not displayed - discoverable by navigating the website
NSW	AQI based on 1-hour average	1-hour average concentration
NT	AQI based on 24-hour average	24-hour average concentration
QLD	AQI based on 24-hour average	24-hour average concentration
SA	AQI derived from all monitored pollutants including 24-hour average $PM_{2.5}$	Not displayed - discoverable
TAS	Not used	10 minute and 1-hour average concentration
VIC	Not used	1-hour average concentration
WA	AQI based on 24-hour average	Not displayed

Main metrics: Air quality categories

70 For the purpose of communicating with the public about air quality, many public health and environmental agencies will categorise air quality measurements into categories using descriptors such as good, fair, poor, unhealthy, or hazardous. These are usually colour coded from green for good – to red or purple for poor. Each State and Territory does this in their own way. The categories can be based on measured concentrations over a 1-hour averaging period, measured concentrations over a 24-hour averaging period, or on the AQI derived from either 24-hour or 1-hour averages. The cut points for defining each category, the names used to describe each category, and the advice associated with each category also varies between states. Table 4 is a summary of the various categories used by each jurisdiction and how they relate to the measured concentration of $PM_{2.5}$

Table 4. Comparison of air quality/action categories and trigger levels across Australian states and territories for $PM_{2.5}$ (µg/m³). Categories have been grouped for the purpose of comparison. (Table prepared by EPA Victoria)

Response / Air Quality Category	ACT (24HR) Based on AQI	ACT (24HR) *	NSW (24HR) Based on AQI	NT (24HR) Based on AQI	QLD (24HR) Based on AQI	SA (24HR) Based on AQI	TAS (1HR)	VIC (24HR) ~	VIC (1HR)	WA (24HR) Based on AQI
Low / Very Good - Fair	0-8.2	0-8.9	0-8.2	0-8.2	0-8.2	0-8.2	0-9	<9	<27	0-8.2
	8.3-16.4		8.3-16.4	8.3-16.4	8.3-16.4	8.3-16.4				8.3-16.4
	16.5-25	9-25.9	16.5-25	16.5-25	16.5-25	16.5-25	10-24	9-25	27-62	16.5-25
Medium / Moderate - Poor	25.1-37.4	26-39.9	25.1-37.4	25.1-37.4	25.1-37.4	25.1-37.4	25-99	>25-40	62-97	25.1-37.4
High / Very Poor	37.5-50	40-106.9 107-177.9	37.5-50	37.5-50	37.5+	37.5+	100+	>40-177	97-370	37.5-50
Very High / Extreme/ Hazardous	50+	>177.9 >250	50+	50+				>177 >250 [a]	370+	50+

Notes. The trigger levels in the table above are presented in µg/m³, however some jurisdictions express this as an Air Quality Index in public reporting.

* *ACT Health, Health Advice for Smoky Air* https://www.health.act.gov.au/about-our-health-system/population-health/environmental-monitoring/monitoring-and-regulating-air-0

~ Emergency Management Victoria, Standard for Smoke, Air Quality and Community Health (Version 2.0) 2019 & Trigger for advice from Chief Health Officer on temporary relocation if $PM_{2.5}$ are predicted or are >250 µg/m³ for two consecutive days.

71 In recognition that the variation in reporting conventions across Australia was a source of confusion for the public during the 2019-20 bushfire and air quality crisis, the Environmental Health Standing Committee (enHealth) of the Australian Health Protection Principal Committee (AHPPC) convened a meeting of key members of health and environmental agencies from States and Territories around Australia in Melbourne on 26 February 2020. I attended that meeting as I was asked to deliver a presentation on the health effects of bushfire smoke, and I also represented the Tasmanian Department of Health.

72 EPA Victoria produced a background document to inform discussions at this meeting. Table 4 (above) is reproduced from that document. The background document noted that during the recent fire season in south-eastern Australia, questions were raised by numerous organisations, the public and media regarding the differences in jurisdictional approaches to the provision of air quality advice and public health messaging and that these differences included:

(a) The use of a monitoring and reporting framework/guideline specifically for bushfire smoke events, vs general air quality information about PM.

(b) The use of one-hour versus 24-hour (or longer) averaging periods.

(c) The use of an Air Quality Index versus measured $PM_{2.5}$ concentrations for public reporting.

(d) The use (or not) of a hazardous/extreme air quality category.

(e) The cut points for defining air quality categories, particularly for moving from a "very poor" to a "hazardous" rating.

(f) The amount and nature of protective health advice provided by jurisdictions along with air quality reports.

(g) The colour coding used for air quality/response categories.

73 A notable difference was that in some jurisdictions a 24-hour average concentration of 50 $\mu g/m^3$ was classified as the worst possible category of 'hazardous' while in other places a concentration above 177 $\mu g/m^3$ was required to be categorised as 'hazardous'.

74 Another important difference was that categories based on hourly averages were different to those based on 24-hour averages. As such, it was possible to find simultaneous reports of both 'good' and 'hazardous' air quality for a particular time and location.

75 At this meeting all jurisdictions agreed to work towards national consistency in this area.

Describe the key way(s) in which air quality information and public health information in relation to air quality is conveyed to the public across Australia in the context of bushfires.

76 Air quality and public health information is conveyed to the public by health and environment agencies in each State and Territory in Australia. These agencies often present the information on their respective agency internet site. Environment agencies generally present data on air quality while health departments present information about protecting health, but there is overlap and cross referencing between these.

77 During a bushfire smoke episode, agencies will often provide health information and alerts through media releases. The triggers for providing media messaging are at the discretion of each agency. It is common for media outlets to seek out information from experts in response to smoky conditions.

78 I have led two research projects that have sought to learn more about how people obtain understand and use information about air pollution associated with bushfire emergencies in Australia, which I describe briefly below:

(a) The first was a small qualitative study conducted during severe air pollution associated with Tasmanian bushfires in 2019. Participants were interviewed within three weeks of the pollution episode to understand (1) the level of concern about the impacts of smoke on health and wellbeing, (2) how information about smoke and health was received and understood, and (3) if public health information influenced individual actions and behaviour. In keeping with previous studies, we found that living through smoky periods was a markedly negative and stressful experience, and that social media was a central method for receiving information[(88)(89)]. We found that people looked to multiple places for information, often consulting local, national and international web pages, and were frequently confused by apparently contradictory information they found. A range of themes emerged from detailed feedback on the public health messaging. These included the perceived lack of timeliness and practicality of some of the information, the desire for more detailed information about health risks and how these related to differing severity of air pollution, and the tension between messaging about the simultaneous fire and smoke hazards in different locations across affected areas. We concluded that public messaging about smoke and health should continue to use multiple avenues of communication, with a focus on simple messages provided through social media. Messaging about the smoke hazard should be available from a trusted central source regarding all aspects of the wildfire emergency, with links to more detailed information including local air quality data alongside an interpretation of the associated health risks. This paper has not yet been published but is currently under review with an international public health journal.

(b) The second was a survey of people who had used the AirRater app for air quality information during the summer fire crisis. They reported that state government websites, traditional and social media were the primary sources of information for air quality. The full range of sources is listed in Box 2 below. It demonstrates that people seeking air quality information check a multitude of sources, some highly reliable and others of variable quality or applicability to Australian circumstance. Consistent with previous evaluations of the app,[16] this survey found that respondents reported that the near real-time information provided through the app was highly useful, and supported informed decisions regarding daily activities during the smoke-affected period such as staying inside, rescheduling or planning outdoor activities, changing locations to less affected areas or informing decisions on medication use. In some States, this app was the on source of information about hourly (as distinct from 24-hourly) averages of $PM_{2.5}$. This work has not yet been published.

79 Both projects described above found a very high use of digital information among participants. This partly reflected the interest of the participants who had either elected to be a part of a research project or chosen to download an air quality app. However, it implies that populations groups or people who are not familiar with technological platforms, have low levels of literacy, or do not have access because of social, economic or language barriers, could miss out on important information for managing their health. This supports the need for ongoing community education in this area, and exploration of new methods of delivery.

Box 2. Sources of air quality information during the 2019-20 bushfire smoke crisis reported by users of AirRater

1. State government health and environment websites

2. Media
   - Traditional media (TV, radio)
   - Social media (e.g. dedicated air quality Facebook page, such as 'My Air Quality Australia')

3. Non-government apps and websites
   - AirRater (University of Tasmania)
   - Purple Air (international commercial network)
   - Air Matters (international site)
   - Canberra Air (Australian blog)
   - The AirVisual (app of the international site iqair.com)
   - AQICN (international website)
   - Breezometer (international commercial site)

4. Other sensors
   - Plume labs
   - AQ sensor on air cleaner (e.g.Dyson)
   - Built own sensor
   - Nose and eyes

Describe limitations or difficulties (if any) with that information and if so, how that information might be improved.

See Table below.

Limitation or difficulty	**Possible improvement**
Understanding the meaning of air quality information	Ongoing community education campaigns (not just during fire emergencies) explaining the health impacts associated with smoke from wood heaters, planned burns and bushfire, what actions can reduce these impacts, and how to interpret and use air quality information.
Poor accuracy of air quality information in regions without a nearby government/official air quality monitoring station.	Improved by government agencies expanding their monitoring networks to provide validated and calibrated air quality data Low cost sensors purchased from commercial companies may be inaccurate or unreliable (e.g. not regularly calibrated, inappropriate detection limits).
Data updated infrequently. 24-hr average not useful and often misleading	Routine provision of at least hourly averaged PM data to the public
Differing units of measurement are presented across different services (e.g. AQI vs $PM_{2.5}$) increase difficulty in understanding	Standardisation of presentation of information across government sites in Australia
Differences in categories of air quality rating between services	Standardisation of category descriptions and ranges across government sites in Australia
Website and services difficult to understand or navigate	Use consumer feedback and focus groups to design websites and services to enable greater accessibility for groups with lower literacy and those with visual impairment
Trustworthiness of information, especially from private websites and blogs.	Promote government agencies as authorised sources of air quality information

Signed by Dr Fay Johnston)
on 23 May 2020)
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