

The Limits of Livability

The emerging threat of smoke impacts on health from forest fires and climate change

'If this is what we experience regularly, we just can't live here. This is not something we can experience regularly. There's no way to maintain the population density in the places that we live if these are the seasonal changes ahead.'⁽¹⁾

Dr Arnagretta Hunter
Cardiologist, ANU, Canberra, Australia

About GCHA

The Global Climate and Health Alliance (GCHA) is the leading global convenor of health professional and health civil society organizations addressing climate change. We are a consortium of health and development organisations from around the world united by a shared vision of an equitable, sustainable future, in which the health impacts of climate change are minimized, and the health benefits of climate solutions are maximised. GCHA works to elevate the influential voice of the health community in policy making to address the climate crisis.

Contact: info@climateandhealthalliance.org
 @GCHAlliance

Authors: Frances MacGuire, Milena Sergeeva

Interviewees:

- Arnagretta Hunter, Cardiologist, ACT, Australia
- Vicki Kotsirilos, General Practitioner, ACT, Australia
- Joanne Walker DPH (Dr Public Health / Research) NSW, Australia
- Noel Webster Indigenous fire stick practitioner NSW, Australia
- Dario Kopenawa Yanomami, Vice President of Hutukara Yanomami association, Brazil
- Jerrimar Soares Montenegro, Nurse, Union Affairs Director in the Union of Nursing Professionals in the state of Rondônia — SINDERON, Brazil
- Marcelo Salazar, Health in Harmony, Brazil
- Fabio Tozzi, Vascular Surgeon, Brazil, Health and Happiness Project

- Sarah Henderson Scientific Director, Environmental Health Services, British Columbia CDC. Associate Professor, School of Population and Public Health, University of British Columbia
- Courtney Howard, Emergency Physician, Yellowknife, Canada
- Melissa Lem, Family Physician, Vancouver Canada

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Photo sourcing: Luisa Colasimone, Jen Kuhl, Milena Sergeeva

Editing: Nicola Baird

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<https://climateandhealthalliance.org/forest-fire-smoke-health-climate/#LimitsofLivability>

FOREWORD

Despite years of pandemic scenario planning by public health departments, most countries were not prepared for the COVID-19 pandemic. This was particularly evident in countries such as the US and the UK, where public health funding has been cut back by successive governments. It is no coincidence then that these two countries have among the highest rates of infection and deaths. In contrast, some of those countries who responded most effectively, such as Taiwan and South Korea, were those who had recent experience of the 2003 SARS pandemic.

Rewind to 2019-20, when the worst bushfires in Australia in living memory ravaged the country. While thousands of lives were saved through the tireless efforts of the fire services, the authorities were not prepared for these serious climate impacts that have been described and predicted by scientists for over three decades.

During the 2019 fires in the Amazon rainforest, the Global Climate and Health Alliance (GCHA) noted that there was scant discussion about the health impacts of the smoke from the fires on people and populations, and little publicly available data. Yet during every fire season, people who live in or near forests are exposed to forest fire smoke pollution. Meanwhile, longer and more intense fires have been recorded in recent years in temperate forests around the world, generating smoke that impacts health in far off cities.

The scale of disasters is usually measured by the number of fatalities, but like the COVID-19 pandemic, the Australian bushfires revealed other far-reaching effects on people and the planet. These include homelessness after evacuation from burned out properties, lost homes and businesses, devastated habitats, and polluted air and water

courses from wildfire smoke. Meanwhile the pandemic has complicated wildfire response.

In a crisis, our focus on the immediate emergencies as they unfold tends to obscure the wider and long-term impacts of disasters. The health and social effects of wildfires persist long after the event. People who are evacuated may not be back in their homes a year on. People who were not insured may be homeless. More attention to the long-term effects of disasters could increase political and public support for prevention in a way that the retelling of heroic rescues, while rightly inspiring, does not.

Both the fires and the pandemic have demonstrated that we need to change our relationship with the natural world on which we depend — for clean air and water, food and building materials, and even the metals for the renewable energy systems which must replace fossil fuels. Both crises also highlight inequalities between people and populations within and between nations.

Of the case studies examined in this report, recent fires in Canada and Australia were in part driven by climate change, while the fires in Brazil were set intentionally, as part of agriculturally driven land clearing, part of a process of deforestation that contributes to climate change.

Cutting across these case studies and the recommendations that emerge, therefore, is the urgent need to mitigate climate change.

Jeni Miller, PhD Executive Director, Global Climate and Health Alliance

'We saw that the fires become a sentinel event for people that changed their understanding of climate change and what it means for themselves and their family. Whether I'm speaking with community members, media, or decision makers, they ask 'So doctor, is this a new normal?' And every single time, I have to say, 'No, it's not, it's going to get worse.' Coming to terms with the inevitability of worsening climate disruption is difficult but key to ensuring a healthy future. Preparation is the prescription.'

(2)

Dr Courtney Howard
ER Physician and wildfire researcher
Chief Drygeese Territory, Yellowknife, Canada

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1.

Executive summary

In 2019, extensive forest fires in the Amazon followed by the worst bushfires in Australia in living memory, fires which raged for five months, sparked international concern. Both devastating events took place to a backdrop of wildfires recorded around the world in 2019 and 2020.

Forest fires in the Amazon are deliberate, driven by land clearing for intensive agriculture and ranching, and contribute to climate change by releasing forest carbon stores. The extreme fires witnessed recently in temperate forests around the world are, in part, fuelled by climate change. The risk of wildfires is projected to increase as climate change intensifies.

Whether a climate change driver, or a consequence of global warming, forest fires now cause episodes of extremely poor air quality that can affect very large populations. In Australia, for example, 80% of the population were affected by smoke pollution in the 2019/2020 fires.

Forest fire smoke contains a range of pollutants including particulate matter, carbon dioxide, nitrogen oxides and volatile organic compounds. It may pollute domestic water tanks and waterways with ash and particulates, as can the fire retardant dropped by planes and helicopters.

Health impacts increase in step with incremental increases in air pollution and are seen especially in children, the elderly and those with existing chronic medical conditions. People

who spend more time outdoors are more vulnerable, along with older people over 65, people with asthma, chronic obstructive pulmonary disease (COPD) and cardiovascular disease. Modest rises in pollution levels can have major population health impacts if enough people are exposed or the smoke persists for a long time.

Short-term impacts from wildfire smoke include coughing and shortness of breath. Wildfire smoke is a trigger for asthma presentations and is associated with an increase in emergency hospital attendance after short-term exposure and particularly for children. Recent studies have found associations with ambulance callouts for respiratory, cardiovascular and diabetic problems. The impact of wildfire smoke on health can be tracked through changes in the number of commonly used pharmaceuticals dispensed to treat respiratory conditions, for example, salbutamol used for relieving asthma symptoms.

Studies have linked exposure to air pollutants to adverse pregnancy outcomes including low birthweight. A recent study of exposure to particulate pollution during wildfire seasons in British Columbia indicated that impacts on respiratory and cardiovascular health were observable within one hour of exposure to $PM_{2.5}$ and an impact on diabetes outcomes were seen over time. Large cohort studies are currently underway in Canada and Australia investigating the impacts of forest fire smoke pollution on birth outcomes.

While there is good evidence of the short term impacts of forest fire smoke the long term impacts are not yet known. This report reviews the existing evidence on the health impacts of forest fire smoke. Three case studies – focussing on forest fires in Canada in 2018 and the 2019-2020 bushfires in Australia (both in part climate-driven), as well as the land-clearing fires in the Amazonian rainforest in Brazil in 2019 – illustrate the impacts on health and health services of prolonged forest fire events. Interviews were carried out with health professionals and Indigenous people in Canada, Australia and Brazil who experienced the forest fire episodes described.

In the Canadian provinces of British Columbia (BC) and Alberta, 2018 was the worst fire season on record, following record-breaking fires in 2017 when a 10 week state of emergency was declared. Smoke from the fire spread across Canada. It burned 1.3 million hectares, and the Interior Health Authority had to close 19 sites, evacuating 880 patients and displacing over 700 medical and health staff at a cost of \$2.2 million US dollars.

The Australian bushfires of 2019/2020 were unprecedented.. Air quality was ten times hazardous levels in state capital cities. Maximum PM2.5 levels in Canberra, Australia's capital were recorded at 2,496 $\mu\text{g}/\text{m}^3$ during the week of Jan 5-11 and prescriptions for inhalers for shortness of breath increased by 73%. The unprecedented ferocity of the fire and persistence of smoke for weeks and months, were described by all those interviewed.

Approximately 27 million people live in the Amazon basin and some 10 million of these live in areas of poor air quality. In the devastating fires of August 2019, health impacts included increased cases of respiratory problems, particularly among children. Studies from the Amazon basin show

that particulate matter from forest burning is associated with low birth weight, increased risk of respiratory disease among children and elderly people and higher rates of outpatient, emergency room visits and hospital admissions, alongside decreased lung function.

Recommendations: Preparation, adaptation, and mitigation are needed to protect people's health from the smoke impacts of worsening wildfires and forest fires.

Key recommendations:

- **Forest protection and management:** Adopt an immediate moratorium on man-made land clearing fires in the Amazon and other applicable regions. Improve fire management practices, including by working with and learning from Indigenous fire managers.
- **Health risk mitigation and adaptation:** Prepare communities and government agencies for effective wildfire and smoke response. (See guides available, e.g., in Australia and the US.) Fire evacuation plans must be refreshed and kept up-to-date and, critically, communicated to residents.
- **Health impact data collection and research:** Study the long term impacts of exposure to forest fire smoke on health and on health services.
- **Global climate action:** Recognise increasing extreme forest fire events as another stark warning of the impacts and health threats of climate change. Align climate mitigation commitments with the Paris Agreement target of limiting global warming to 1.5 Celsius. Measures that strengthen health, wellbeing, and healthcare systems in the near term while meeting climate mitigation targets should be prioritized.

2.

Introduction





In 2019, extensive forest fires in the Amazon sparked international reaction, eliciting widespread concern about the destruction of the Earth's largest and most biodiverse rainforest.⁽³⁾ Images of the fires shocked the world, prompting several European nations, including France and Ireland, to threaten cancellation of a key trade deal unless Brazil took effective action to stop the burning. Smoke from the fires was recorded as having circumnavigated the globe. In 2020, the fires were reported to be just as bad, but global attention had shifted, as nations grappled with the COVID-19 pandemic.⁽⁴⁾

Forest fires in the Amazon are deliberate, driven by land clearing for intensive agriculture and ranching, and contributing to climate change by interfering with the important role the forest plays as a carbon store. In contrast, the ever more extreme fires witnessed recently in temperate forests around the world are, in part, driven by climate change. In 2017 fires in western Canada prompted a 10-week state of emergency. The 2017 Portuguese fires, the 2018 Chilean fires, and the 2018 and 2019 Western US fires were all globally extreme, each outdoing previous fires, and all largely climate driven. Whether a climate change driver, or a consequence of global warming, forest fires result in significant health impacts. Underappreciated are the short- and long-term public health impacts from exposure to forest fire smoke, as far greater populations are exposed, more repeatedly and for longer periods of time.

The Amazon fires took place against a backdrop of record-breaking temperatures and fires around the world, including in southern Europe, Indonesia, Siberia and the Democratic Republic of Congo. The Amazonian fires were then eclipsed by Australia, where fires raged for five months from October to February, killing 33 people, including firefighters. More than 3,000 homes were destroyed and three billion animals reportedly died or were displaced.⁽⁵⁾ Smoke from these fires was estimated to have been responsible for more than 400 deaths.⁽⁶⁾ Bushfire smoke polluted state capital cities and was traced

'Even if someone is far from a fire source, they may still experience adverse health outcomes from the inhalation of highly diluted and oxidised smoke.' ⁽⁷⁾

Athanasios Nenes

Atmospheric chemist at the Swiss Federal Institute of Technology Lausanne

to New Zealand, where the particulate pollution turned white alpine snow fields to an ashy pink.

Climate change is expected to drive more frequent and severe forest fires putting larger populations at risk, particularly those at the edge of urban areas.^(8,9) Forest fires may start from lightning strikes, but also through deliberate burns to protect property from extreme events and clearing land for agriculture.^(7,10)

'Human health impacts of fire include death, trauma, and major burns, anxiety during wildfire periods ... post-traumatic stress disorder, anxiety and depression related to evacuations'. ^(11,12)

When forest fires occur, the immediate concern is to prevent loss of life from the fires themselves and falling trees and to protect property, livestock and

wildlife. Air pollution from smoke is a recognised impact, but previously has largely been regarded as a short-term, unpleasant discomfort, with reversible effects.

However, smoke episodes now last not just for days, but for weeks and months. Fires burning in rural forest areas generate so much smoke that distant cities have observed darkened skies and air pollution spikes which have affected people's ability to breathe.⁽⁷⁾ Long range transport of fire smoke from forests has always happened and episodic smoke is an feature of life in some cities in forested countries. What has changed is that fire episodes are longer, creating more extreme smoke events with the potential for significant public health impacts.

Wildfires are recognized as a global problem which crosses international boundaries. Smoke plumes from large wildfires can rise kilometres up into the air, reaching the stratosphere where currents spread the smoke around the globe. In 2019/2020, Australian bushfires generated a smoke cloud that was 1,000km wide, stayed intact for three months, travelled 66,000km and rose to 35km above Earth.⁽¹³⁾

Superheated smoke and ash rising high into the air can trigger fire-induced thunderstorms (known as pyrocumulonimbus events) and lightning, which can cause new fires or fuel existing ones.^(14,15) 'The storm can move rapidly, accumulating embers and materials from the fires at surface level and spitting them out kilometres away, spreading the conflagration still further'.⁽¹²⁾

'In 2019, smoke from wildfires in Alberta, Canada was tracked across the Atlantic and into Europe'.⁽⁷⁾ In 2020, smoke from the US was tracked across the UK.⁽¹⁶⁾ Wildfire smoke can cause ambient air pollution and associated health impacts at far as 1000km from the fire itself.⁽¹⁷⁾

The frequency and intensity of wildfires is predicted to increase as climate change drives longer, warmer and drier seasons.⁽⁹⁾ More fires will contribute to climate change as the carbon stored in trees and soil is lost to the atmosphere.⁽¹⁸⁾ Forest fire risk reduction includes practices such as controlled or prescribed burning, also known as hazard reduction burning, which also creates smoke pollution, so the need for fuel management is itself increasingly resulting in even more population level exposure to smoke.⁽¹⁹⁾ As more fires burn around the world fire seasons are beginning to overlap.⁽²⁰⁾ This is resulting in millions more people being exposed to harmful smoke for longer periods, with potential long-term impacts on their health.

Most research on forest fire smoke and health is fairly recent, with small groups of researchers around the world specialising in this area. With the growing recognition that smoke knows no boundaries, persists for long periods of time in the atmosphere, and travels vast distances, these researchers are connecting globally to increase knowledge and to inform policy makers and public health services.

This report draws upon the research to date to provide an overview of the links between forest fires, climate change and the impacts on human

health from smoke pollution. The focus is on the short and long-term impacts on health of smoke, an issue which receives little attention once the dramatic images of flames and darkened midday skies have faded from memory for all but the people that were there.

The long-term effects of wildfire smoke are still not well-studied.^(21,22) Interviews with forest fire smoke researchers, medical and health professionals, and indigenous fire management experts were conducted, to provide a more vivid picture of the challenge. Three case studies — focussing on the forest fires that overwhelmed western Canada in 2017 and 2018 and the 2019-2020 bushfires in Australia (both in part climate-driven), as well as the land-clearing fires in the Amazonian rainforest in Brazil in 2019 — are included to illustrate the impacts on health and health services of prolonged forest fire events to inform national decision-making on climate change and fire preparation, and response at the national and international levels.

'I saw a lot more people with (upper) respiratory complaints like stuffy, runny noses to constant sore throats, worsening coughs and lots of calls for inhaler refills, sooner than they would expect.' ⁽²³⁾

Dr Melissa Lem
Family physician
Vancouver, British Columbia

3.

The Impacts of Forest Fire Smoke on Human Health



3.1 Forest fires, smoke pollution and health

'There is a comparatively small body of public health evidence specifically addressing the health impacts of severe forest fire smoke events.' ⁽²⁴⁾

At the beginning of this century, there was widespread discussion and analysis of the impact of air pollution on health, though not of the impact of smoke from landscape fires (forests, peatland and savannah). As forest fires have become more frequent and intense, and as more people are living in, or near, densely forested areas, large smoke events affecting major population centres are becoming increasingly common.

Forest fires can cause episodes of extremely poor air quality that can affect very large populations. In Australia, for example, 80% of the population were affected by wildfire smoke pollution in 2019.⁽²⁵⁾ Wildfire smoke contains a range of pollutants including particulate matter, carbon dioxide, nitrogen oxides and volatile organic compounds.⁽²⁵⁾ Wildfire particulate matter may be more harmful to health than urban particulate air pollution.⁽²⁶⁾

Forest fire smoke can also pollute domestic water tanks and waterways with ash and particulates, as can the fire retardant dropped by planes and helicopters. In Australia, following bushfires, ash is frequently washed up on beaches from the ocean and also appears in storm water drainage systems.

Wildfires can lead to dramatic spikes in the amount of particulate air pollution. It is widely known among forest fire epidemiologists that exposure to any incremental increase in air pollution can cause adverse effects on human health, especially in babies, children, the elderly and those with existing chronic medical conditions.⁽²⁷⁾ Health impacts increase in step with increases in air pollution, so modest rises in pollution can have huge population



PC: Bruno Kelly - Amazônia Real - 2020

health impacts if enough people are exposed or the smoke persists for a long time.⁽⁶⁾ The added pollution levels need not be high to impact health. In the 2019/2020 Australian bushfires, for example, 85% of the estimated mortality from air pollution was modelled at concentrations that were mildly or moderately elevated above background — $\text{PM}_{2.5}$ at $50 \mu\text{g}/\text{m}^3$ or lower, rather than on the extreme days when $\text{PM}_{2.5}$ reached $1000 \mu\text{g}/\text{m}^3$.⁽²⁸⁾ Pollution levels on these extreme days did not drive the big health impacts seen, rather, it was the sheer number of vulnerable people exposed that drove the high estimate of mortality.

Of special concern are particles known as $\text{PM}_{2.5}$ (particulate matter of 2.5 microns or less), which are invisible to the naked eye. These are particularly

harmful to human health, and may affect every organ in the body; they can penetrate the lungs, cross into the bloodstream, circulate throughout the body, and cross the blood-brain barrier.⁽²⁶⁾ Smoke particles from forest fires along with many other reactive and irritant chemical compounds from the burned wood and foliage promote inflammation and oxidative stress in lungs and throughout the body.⁽²⁹⁾ One study, for example, from researchers in British Columbia, Canada showed that for every $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ from wildfire smoke, there is a 6% increase in asthma related admissions.⁽³⁰⁾ In British Columbia, particulate levels can be 20 times higher in wildfire season than average levels, leading to spikes in asthma related admissions.⁽⁷⁾ Studies from the US and Australia have shown similar results.

3.2 Health outcomes

Epidemiological studies indicate that landscape fire smoke causes an estimated 339,000 premature deaths per year worldwide, far more deaths than those lost directly in the blazes. Yet smoke from fires receives relatively little attention. A high proportion of annual premature deaths from forest fire smoke have been estimated for sub-Saharan Africa (157,000) and SouthEast Asia (110,000) and it 'could be shortening life expectancies for populations that experience fire seasons regularly'.⁽³¹⁾

Young children are at higher risk from smoke exposure because they tend to have a higher breathing rate and their organs are still developing. People spending more time outdoors, such as outdoor workers or people who are homeless, are more vulnerable, along with older people over 65, people with asthma, chronic obstructive pulmonary disease (COPD) and cardiovascular disease.⁽²⁶⁾

'Fire emissions are an important contributor to global mortality. Adverse health outcomes associated with landscape fire smoke (LFS) could be substantially reduced by curtailing burning of tropical rainforests, which rarely burn naturally.'⁽³¹⁾

Females seem to be more sensitive to asthma related outcomes than males.⁽³²⁾ Studies have linked exposure to air pollutants to adverse pregnancy outcomes including low birthweight,⁽³³⁾ and a more recent study showed an association between low birth weight

Box 1: Populations most at risk from forest fire smoke⁽²⁶⁾

Infants and Children
Outdoor workers
Homeless people
People with pre-existing conditions e.g. asthma, COPD, CVD.
Pregnant women
People in poor housing and with low health literacy who may not be able to take preventative measures
Adults over 65

'What I do know, subjectively, as someone who lived through it, is that most people had a cough, and most people were a bit short of breath. And my biological suspicion is that it causes long-term fibrosis. We will know in five or 10 years whether that starts to have a population effect.'⁽¹⁾

Dr Arnagretta Hunter
Cardiologist, ANU, Canberra, Australia

(LBW) and maternal exposure to air pollution (PM_{2.5} and carbon monoxide (CO)) from biomass burning during the second and third trimesters of pregnancy.⁽³⁴⁾

Short-term impacts from wildfire smoke include coughing and shortness of breath. Wildfire smoke is a trigger for asthma presentations and is associated with an increase in emergency hospital attendance after short-term exposure and particularly for children.⁽³³⁾

In an interview, Dr Sarah Henderson, senior scientist in environmental

Box 2: Smoke health impacts and areas of ongoing research

- People with chronic respiratory conditions seem to be the most sensitive group to exposure to forest fire smoke.⁽²⁴⁾ In Australia, some 30% of the population have underlying respiratory conditions and 10% of the population are affected by asthma.

- Studies have shown that smoke events are associated with an immediate increase in presentations to hospital for respiratory conditions. In comparison, attendances for cardiovascular disease lag by around one to three days.^(17,35,36) Smoke also causes eye irritation and corneal abrasions.⁽²⁶⁾

- There may be a misconception that smoke from burning wood is less harmful than other air pollution because it is as perceived as 'natural'. There is some evidence that fire smoke from biomass may cause greater health effects than air pollution from traffic or industrial sources.⁽³²⁾

- Low birth weight is seen as a sensitive indicator of adverse health effects during pregnancy. There is evidence to suggest air pollution alters how well the placenta functions. This could affect blood flow to the developing baby and may cause fetal growth restriction and low birth weight.⁽³⁷⁾

- Researchers investigating the impacts of wildfire smoke may investigate various health outcomes e.g. for emergency room presentations these may include all respiratory conditions (asthma, COPD, pneumonia, bronchitis); all cardiovascular conditions (ischemic heart disease, arrhythmias, cardiac failure); and cerebrovascular diseases. Research is hampered by the lack of air quality monitoring systems in or close to forested areas.

- In Australia, prior to 2019/2020, forest fires were most often short-term exposure events even though large cities could be affected. Smoke events may influence the overall workload of hospital emergency departments. Experience from one study in Sydney, Australia saw a 1-3% increase in workload which persisted for four days.⁽²⁴⁾

- Smoke events that last for weeks or months are likely to have much higher impact. A retrospective cohort study of the health impacts from a severe and prolonged wildfire season in the sub-Arctic describes one of the longest exposures in the literature base. Emergency room visits for asthma doubled over the 2.5 months of the fire season as compared to surrounding years.⁽³⁸⁾ Several studies are due to be published in 2021 on the impacts of fires of longer duration.

health services at the British Columbia Center for Disease Control, indicated that some people with pre-existing respiratory conditions may never completely recover from the impacts of just one severe wildfire event.⁽³⁹⁾ Cohort studies are currently underway in Canada and Australia investigating the impact of wildfire smoke on health and birth outcomes.^(1,39)

Recent studies have found associations with ambulance callouts for respiratory, cardiovascular and diabetic problems.⁽³⁶⁾ In Australia, during the fires at the end of 2019, hospital admissions due to breathing problems increased by 34% in the state of New South Wales.⁽⁴⁰⁾


The impact of wildfire smoke on health can also be tracked through changes in the number of commonly used pharmaceuticals dispensed to treat respiratory conditions, for example, salbutamol used for relieving asthma symptoms. Salbutamol dispensations increase with fire-related $PM_{2.5}$.⁽⁴¹⁾

There is no safe level of exposure to $PM_{2.5}$, no threshold, so to reduce the risk of death and disease the risk of exposure must be reduced.⁽²⁹⁾

Measures are needed to reduce the occurrence of forest fires and to protect people from smoke pollution, particularly, $PM_{2.5}$, in the midst of fires.



PC: BC Wildfire Service



'It was so hot; it had not rained and there was no water. We had plants and trees dying, animals dying, people would find dead birds on the streets. It got too hot for [pet] animals too. You can't go outside, you can't breathe the air, the water's unreliable. That really starts to get to the edge of what you want to go through.' ⁽¹⁾

Dr Arnagretta Hunter
Cardiologist, ANU, Canberra, Australia

3.3 Climate change and forest fires

The risk of wildfires is projected to increase in most areas of the world as climate change intensifies ^(9,42) bringing more frequent heat waves of longer duration ⁽⁴³⁾ and changes in rainfall patterns which affect vegetation growth. According to the IPCC: 'In high-latitude regions, warming is projected to increase disturbance in boreal forests, including drought, wildfire, and pest outbreaks (high confidence)'.⁽⁴⁴⁾

'Without immediate actions to limit the global temperature increase, the interplay between wildfires and climate change is likely to form a reinforcing feedback loop, making wildfires and their health consequences increasingly severe'.⁽²⁶⁾

Current levels of climate change are associated with moderate risks from increased dryland water scarcity and wildfire damage. Projections from the IPCC indicate that a 1.5°C increase in global temperature would lead to high risk of wildfire damage, and a 3°C increase to a very high risk of wildfire damage.⁽⁴⁴⁾ Under a scenario of high greenhouse-gas emissions, wildfires are projected to increase substantially across 74% of the world's land mass by 2100.⁽⁴⁵⁾

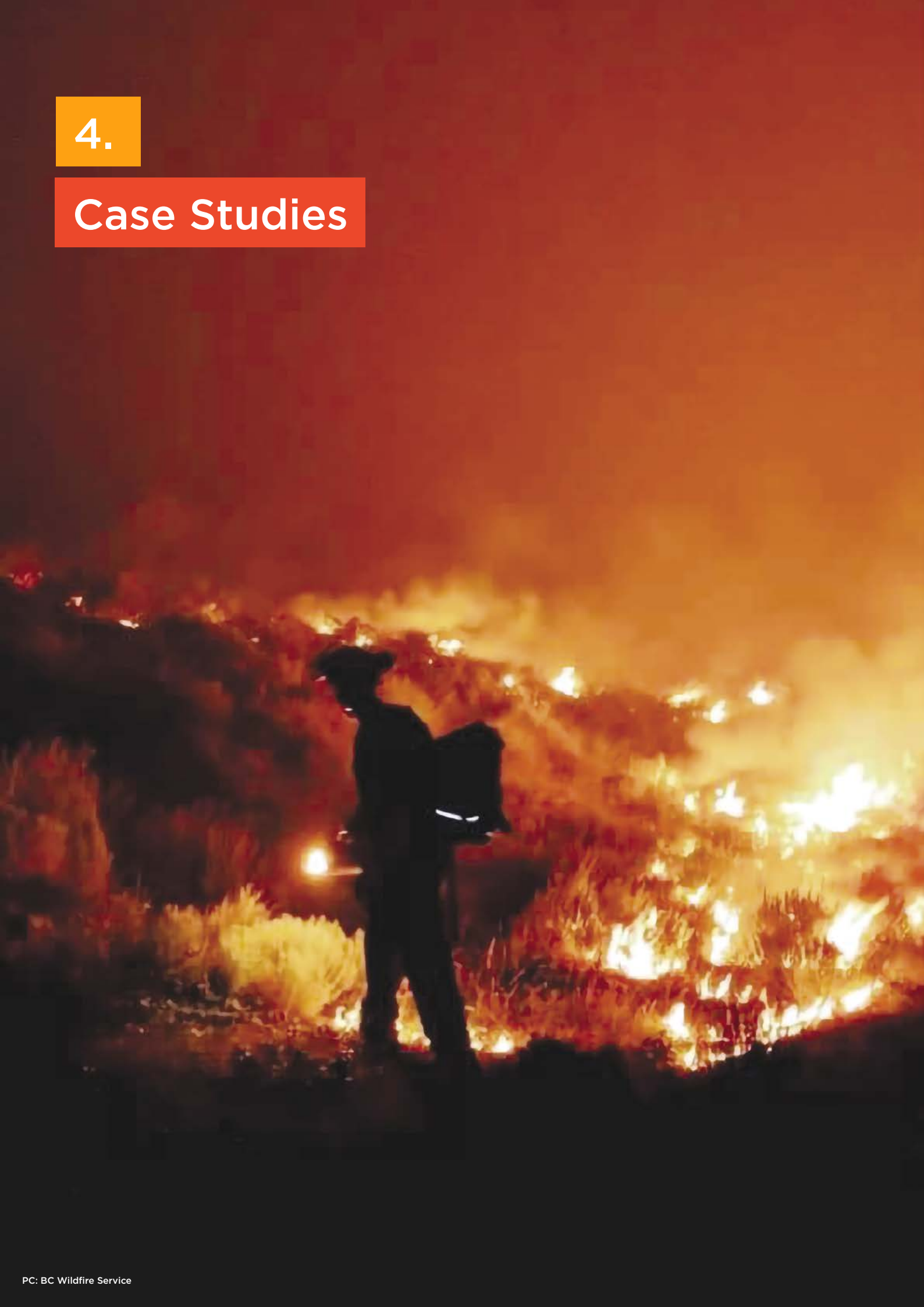
Wildfires drive forest loss which can release substantial greenhouse gas emissions. These may cause more wildfires in a reinforcing feedback loop.⁽⁹⁾ Stronger winds are anticipated with climate change and these can

encourage the spread of wildfires, which may outstrip firefighting capability.⁽⁴⁶⁾ Man-made forest fires, such as used for deforestation and land use conversion for crops and livestock, similarly contribute to climate change, destroying important carbon stores and releasing greenhouse gases into the atmosphere.



4.

Case Studies





Exceptional fires have been recorded in recent years around the world with international attention captured by exceptional fires in Canada in 2018, in Australia in 2019-2020 and in Brazil in 2019.⁽²⁶⁾

The following case studies of these events offer added insight into the health impacts of forest fire smoke, and the policy responses needed to address the challenge.

Table 1 provides a snapshot of a range of health impacts from the smoke from these fires in each of the three countries. It also highlights areas where additional research would be useful as there appear to be gaps in the availability of information.

Table 1: Comparisons of smoke impact from forest fires in the three case studies and gaps in data availability from specific fire events

	Australia 2019-2020	Brazil 2019-2020	British Columbia, Canada 2018
Extent of fire	Over 92,600 square miles burnt (24 million hectares) ⁽⁵⁾	Over 2100 square miles burnt (550,000+ hectares) [Human Rights Watch]	5228 square miles burnt (1,354,284 hectares) ⁽⁴⁷⁾
PM_{2.5}	2,496 µg/m ³ (max reading for week) ⁽⁴⁸⁾	570 µg/m ³ (24 hr mean) ⁽⁴⁹⁾	No estimate found
Bushfire smoke related excess deaths	417 (153-680) ⁽⁶⁾	No estimate found	No estimate found
Hospital admissions linked to smoke from wildfires	2027 (0-4252) for respiratory 1124 (211-2047) for cardiovascular 1305 (705-1908) for asthma hospital presentations ⁽⁶⁾	2,195 (1,098-3,291); (21% infants 0-12 months, 49% 60+) for respiratory ⁽⁵⁰⁾	No estimate found
Hospital days	No estimate found	6,698 (1,292-12,105) ⁽⁵⁰⁾	No estimate found
Average cost	AU\$1.95 billion (US\$ 1.5 billion) in health costs ⁽⁵⁾ Insurance claims from the fires estimated at AU\$ 2.2 billion (US\$ 1.7 billion) ⁽⁵¹⁾	R\$ 5.64 million (US\$ 1.4 million) ⁽⁵²⁾	Total costs of wildfire suppression CA\$ 615 million (US\$ 491.5 million) ⁽⁴⁷⁾
Increased inhaler use (preventers/relievers)	People with asthma 94% were more likely to report respiratory symptoms and seven times more likely to report requiring medication ⁽⁵³⁾	No estimate found	Salbutamol prescription dispensations increased by about 50% in the pharmacies in areas impacted by the fires ⁽³⁸⁾
Impact on health system	No estimate found	No estimate found	2017 BC wildfires resulted in 700+staff displaced 880 patients evacuated 19 sites closed by the Interior Health Authority Cost CA\$2.7 million (US\$ 2.2 million) ^(BCIHA, cited in 57)



'Wildfires cause episodes of the worst air quality that most people living in high income countries are ever going to see'.⁽³⁹⁾

Sarah Henderson
Scientific Director, Environmental Health Services, British Columbia CDC. Associate Professor, School of Population and Public Health, University of British Columbia

4.1 Canada

Polar regions are projected to warm faster due to climate change than areas towards the equator. Located near the Arctic, Canada is warming faster than many other parts of the world.⁽⁵⁴⁾ Under the IPCC scenario where greenhouse emissions continue at a mid-range, it is projected that wildfires will increase in Canada by 75% by 2100.⁽⁵⁵⁾ In the period 1980-2017, 448,444 Canadians were evacuated due to wildfires. Half of these evacuations took place in the last decade, reflecting a trend of increased impact.⁽⁵⁶⁾ Wildfires were included as one of the key indicators of climate-related health impacts in the 2019 Lancet Countdown report from Canada.⁽⁵⁷⁾

4.1.1 Recent extreme wildfire events

In the Canadian provinces of British Columbia (BC) and Alberta, 2018 was the worst fire season on record, following record-breaking fires in 2017

when a 10 week state of emergency was declared.⁽⁵⁸⁾ The fires were fuelled by changed weather patterns driven by climate change, combined with poor forest management. Wildfires caused severe smoke which forced the cancellation of flights and impacted tourism.⁽⁵⁹⁾ Smoke from the fires spread across Canada and as far as Ireland.

The BC Wildfire Service reported that during 2018:⁽⁶⁰⁾

- 2,117 fires burnt more than 1.3 million hectares of land; in 2017, 1.2 million hectares were destroyed.
- 66 evacuations were ordered, affecting 2,211 properties.
- Wildfire suppression cost CA\$ 615 million (US\$ 491.5 million)

To fight the fires, 270 aircraft and 4,756 personnel were engaged. International assistance arrived from Washington State, Mexico, New Zealand, and Australia.

4.1.2 Evidence and experience of health impacts

A recent study of exposure to particulate pollution during wildfire seasons in British Columbia indicated that impacts on respiratory and cardiovascular health were observable within one hour of exposure to increased PM_{2.5} and an impact on diabetes outcomes were seen over time.⁽³⁶⁾ There is some evidence of a link between diabetes and particulate pollution.^(35,61,62) In addition, during sustained wildfire events and smokey conditions, people with diabetes may not be able to follow their usual self-care regimens for exercise and food choices.

Current public health advice for wildfires is based on shorter and less severe fire episodes. In 2014, fires burned for 2.5 months in the area surrounding Yellowknife, in Canada's subarctic.⁽³⁸⁾ According to the results of a qualitative study of community interviews conducted in partnership with the Yellowknives Dene and the Ka'a'gee Tu First Nation which was published by a team of researchers including Dr Courtney Howard, (one of the physicians interviewed for this report), people found it hard to follow public health guidance on staying indoors for such a long time. Northern Canada has long winters and short summers, so access to the outdoors during the lighter days is particularly important.

Analyses of PM_{2.5} air concentrations during Yellowknife's 'summer of smoke' showed that an increase of 10 µg/m³ was associated with an 11% increase in asthma-related ER visits, a 6% increase in pneumonia-related ER visits and an 11% increase in COPD-related hospital admissions.⁽³⁸⁾ Asthma cases presenting to the ER doubled during the fires and salbutamol prescription dispensations went up by about 50% in the community pharmacies, compared to surrounding years. Land-based food gathering and grocery store supply chains were impacted, and community members described increases in mental health impacts from isolation, decreased physical activity and reduced connection to the land, particularly for Indigenous people.⁽¹²⁾

Interviews from the Summer of Smoke⁽³⁸⁾ study demonstrated that advance preparation, including the development of evacuation plans and a strong community plan, were helpful in building individual and community resilience: community members who knew the evacuation plan and how to 'fire-smart' their homes were much more confident and positive in their tone.⁽¹²⁾ Planning authorities will also need to future-proof hospital design and buildings in anticipation of a changing climate. As Dr Howard pointed out, during the Yellowknife fires, for example, smoke entered the hospital operating theatre which meant it could not be used for several days.



PC: BC Wildfires Service

Box 3: Key statements from Australia's Royal Commission into National Natural Disaster Management Arrangements (also known as the Bushfire Royal Commission)

The fires started in Australia's hottest and driest year on record, with much of the country that burnt already impacted by drought. On some days, extreme conditions drove a fire behaviour that was impossible to control. Thirty-three people died, including six Australian firefighters and three American aerial firefighters. Smoke blanketed much of Australia, including capital cities, and contributed to hundreds of deaths.

Thousands of Australians — locals and holidaymakers — became trapped. Communities were isolated, experiencing extended periods without power, communications, and ready access to essential goods and services, or access to cash or card payments, making it impossible to pay for their most basic needs. When around 4,000 people were forced to shelter on the Mallacoota foreshore, the Australian Defence Force evacuated over 1,100 people by sea and air. Estimates of the national financial impacts are over AU\$10 billion (US\$ 7.7 billion).

The summer of 2019-2020 provided only a glimpse of the types of events that Australia may face in the future.

Individuals need to:

- Understand the environment in which they live, and buy adequate home and contents insurance.
- Know when and how to evacuate, and when it might be safe to 'stay and defend'.
- Understand emergency warnings and what to do in response.
- Consider carefully where to live and how they should build their homes, in light of the risk of natural disasters.



4.2 Australia

'Smoke is just one of many problems that will intensify with the increasing frequency and severity of major bushfires associated with climate change. Expanded and diversified approaches to bushfire mitigation and adaptation to living in an increasingly hot and fire-prone country are urgently needed'.⁽⁶⁾

In 2020 Australia's Royal Commission into National Natural Disasters was established in response to the bushfires of 2019-2020, in recognition of the devastating 'loss of life, property and wildlife and environmental destruction'.⁽⁵⁾ The Royal Commission noted that Australia endured the worst wildfire season in recorded history with 33 lives lost, 3,000 homes destroyed, and an estimated three billion animals killed or displaced. Air quality was ten times hazardous levels in Melbourne, Canberra and Sydney. As communities recovered and rebuilt from the crisis, impacts were also noted on mental health.

The Commission reported to the Australian Parliament on 30 October 2020.⁽⁵⁾ Key statements from the 500+ page report are included in Box 3 and key findings on smoke pollution and Indigenous fire practice are given in Box 4 and Box 5.

Some health impacts were estimated to cost nearly AU\$ 2 billion (US\$ 1.55 billion).⁽⁵¹⁾ Insurance claims from the fires were estimated at AU\$ 2.2 billion (US\$ 1.7 billion).

Box 4: Key statements on air pollution from Australia's Royal Commission into National Natural Disaster Management Arrangements (also known as the Bushfire Royal Commission)

The unprecedented 2019-20 Australian bushfires ... saw intense smoke and air pollution hit areas of Australia. While the immediate threat to life has passed, the long-term impacts on our health are not yet fully known.' ⁽⁶³⁾

During the fires:

- 80% of the population of the country affected by poor air quality
- 429 premature deaths, 3,320 hospital admissions for cardiovascular and respiratory conditions and 1,523 presentations to emergency departments for asthma estimated
- AU\$ 1.95 billion (US\$ 1.51 billion) in health costs, associated with premature loss of life and admissions to hospitals
- People with asthma: 94% more likely to report respiratory symptoms and seven times more likely to report requiring medication (Asthma Australia's Bushfire Survey)

Needs and recommendations:

- Greater consistency in emergency warnings and air quality information to allow communities to take preventative action, such as seeking cleaner air spaces, sealing an indoor environment, or taking preventative medication
 - » develop close to real-time, nationally consistent air quality information,
 - » greater community education and guidance,
 - » targeted health advice to vulnerable groups.
- Smoke Plans, including identification and preparation of clean air locations for those needing to seek shelter — such as libraries, shopping malls, community centres, or schools that have tightly sealed windows and appropriate heating, air-conditioning and ventilation systems fitted with high-efficiency particulate air (HEPA) filters.
- Invest in research — AU\$ 3 million (US\$ 2.4 million) was committed to study
 - » identifying and treating the physiological impacts of bushfire smoke
 - » respiratory impacts of bushfire smoke on vulnerable groups
 - » physiological impacts of bushfire smoke on emergency responders and outdoor workers
 - » efficacy of facemasks in filtering bushfire smoke.

4.2.1 History of extreme bushfires

Although bushfires are characteristic of Australia's natural environment, the risk has increased as climate change is driving longer fire seasons that start earlier and finish later.⁽²⁹⁾ Until fairly recently, Sydney was recorded as having severe pollution from fires on average for around 4-5 days in any one year.⁽⁶⁴⁾

In February 2009, a fire that became known as 'Black Saturday' was the second largest fire in Australia with 173 deaths and over 350,000 hectares devastated. The death toll was nearly five times as high as the 2019/2020 fires, but the fires and the smoke production was less prolonged.⁽¹¹⁾

The 2019-2020 bushfires, coined the 'Black Summer' fires, exposed millions of people to hazardous levels of air pollution^(29,65) with 80 per cent of Australians affected by the bushfire smoke over the season.⁽⁶⁶⁾

The 2019-2020 bushfires burned for 19 weeks in many forested areas of the country impacting people across the states of New South Wales (NSW), Queensland, the Australian Capital Territory and Victoria. Levels of PM_{2.5} frequently exceeded the national air quality standard of 25 µg/m³. On 14 January, 2020, for example, PM_{2.5} exposure was recorded as 98.5 µg/m³ which is fourteen times the historical population-weighted mean 24-hour PM_{2.5} value of 6.8 µg/m³.⁽⁶⁾

Between November 2019, when the emergency started, and 8 January 2020, NSW Health announced that it had issued 15 health warnings and

distributed one million P2 masks to bushfire areas.⁽⁴⁰⁾ Response plans included issuing a temporary special authority to pharmacists to be allowed to supply increased quantities of prescription medicines.

Hospitals were reported as coping well although with increased emergency presentations. The number of patients attending for asthma and other breathing problems increased by 34.5% from a daily average of 829 (averaged over 5 years) compared to the daily average of 1,115 (averaged from Dec 30 to Jan 5).

Government bodies offered conflicting information. NSW Health claimed 'Short-term exposure to bushfire smoke or poor air quality are not known to have any long term health effects and there is evidence to suggest that even after long term exposure for many years, people's health improves when their exposure is reduced.' Meanwhile, the Australian Institute of Health and Welfare, the federal government agency on data and statistics declared that: 'The unprecedented 2019-20 Australian bushfires, for example, saw intense smoke and air pollution hit areas of Australia. While the immediate threat to life has passed, the long-term impacts on our health are not yet fully known'.⁽⁴⁸⁾

'I had a couple of women who were pregnant at the time, and asking me, you know, is there a concern for my baby being exposed to air pollution from bushfire smoke? And the answer is basically, in short, yes, pollution can impact the growth of the baby. The effect is similar to exposure to smoking.'

At the time I had pregnant women who were feeling quite anxious and concerned. And basically, the best advice I gave them was to stay indoors, keep windows closed, and if necessary to go out e.g. for shopping, to minimise duration of staying outdoors during high pollution days and consider wearing a P2 mask. There may be a role for air purifiers in the home as well.'

(67)

Dr. Vicky Kotsirilos

General Practitioner, ACT Melbourne, Australia

4.2.2 Evidence of health impacts and status of research to date

During Australia's bushfire season, mortality rates increase with high bushfire smoke pollution as do admissions to hospital, emergency attendances, ambulance call-outs and visits to general practitioners.⁽²⁹⁾

The Australian Institute of Health and Welfare (AIHW), the Australian Government's health and welfare statistics agency, released a set of interactive graphs in its assessment of the short-term health impacts of the bushfires. Maximum PM_{2.5} levels in Canberra, Australia's Federal Capital city, were recorded at 2,496 µg/m³ during the week of Jan 5-11 and prescriptions for inhalers for shortness of breath increased by 73%.⁽⁴⁸⁾

The AIHW expects that, 'there are likely to be a range of long-term health effects from the 2019-20 bushfires that will not be evident for some time'. Studies of lung function among fire-fighters have shown that function can return to baseline over a long follow-up but the cumulative impact of repeat effects is unknown.⁽⁶⁸⁾ A large-scale research project has been funded to look at the medium-term health impacts of smoke and ash exposure, including mental health, for frontline responders and affected communities.⁽⁴⁸⁾

Further research to assess the long term health impacts of the smoke was delayed to 2021 because of the need to focus on the COVID-19 pandemic.

'We lost a lot of trees ... some of our art sites were destroyed by fire, a lot of our cultural resource gathering zones are no longer there, they've been destroyed — so have all the animals, it's like the stories' connection are all gone. So, a lot of communities are struggling and too heartbroken to go out and have a look and see the real impact of what's going on'. ⁽⁶⁹⁾

Noel Webster
Indigenous fire stick practitioner
New South Wales, Australia





PC: Getty Images

4.2.3 Emergency preparation and response

The AIHW found that frequently updated air quality data and forecasts enabled individuals to manage their exposure to hazardous levels of air pollution. Real time data was used to inform evacuation alerts by text message. Available data included bushfire burn-area mapping, air-quality, pharmaceutical, Medicare and hospital emergency department data.⁽⁴⁸⁾

In addition, 'To support access to medications during the 2019-2020 bushfires, the Therapeutic Goods Administration (TGA) gave temporary permission (Therapeutic Goods

(Restricted Representations — Salbutamol) Permission 2020) to advertise the availability of salbutamol inhalers (asthma medication).

This allowed for public health campaigns to remind people to bring their inhalers with them in the event of evacuation and to advertise the continued dispensing provisions for these medicines, which helped to discourage stockpiling and over-ordering.⁽⁵⁾

'More government investment is needed in air quality monitoring, forecasting and research on public health messaging, and exposure reduction measures to protect Australians from bushfire smoke'.⁽²⁹⁾

Australia's health protection advice is currently limited to advising on short-term exposure of a few hours or days. The 2019-2020 bushfires created smoke conditions that lasted for weeks and months.

Box 5: Good practice

In response to the fires the Analysis and Policy Observatory published a practical guide for governments, fire and land management agencies and communities to help reduce the risk of bushfires under worsening climatic conditions which is summarised here.⁽⁷⁰⁾

Readiness

- Create an Indigenous-led National Cultural Fire Strategy to complement and inform fuel management by agencies
- Increase the affordability and uptake of insurance for properties in disaster prone areas, a key factor in community resilience
- Review and update Australian building standards in bushfire-prone areas

Response

- Better resource fire and land management agencies to manage fuels, and rapidly detect and attack new outbreaks
- Add a self-sufficient Australian medium and large aerial firefighting capability to fire services
- Better utilise Australian Defence Force support capabilities in emergencies

Recovery

- Set up a national climate disaster fund to meet climate-fuelled disaster costs and build resilience—paid through a fossil fuel producer levy
- Better coordinate and resource wildlife recovery efforts
- Develop and implement a national climate change, health and well-being strategy

'While unprecedented, this tragedy was not unforeseen. For decades climate scientists have warned of an increase in climate-related disasters, including longer and more dangerous bushfire seasons.'





PC: Cícero Pedrosa Neto - Amazônia Real - 2020

4.3 Brazil

'The peak of hospitalizations of Indigenous people for disease such as asthma, pneumonia, influenza, acute bronchitis, acute bronchiolitis and other acute respiratory infections coincides with the period of forest fires'.⁽⁷¹⁾

While the extreme wildfire events in Australia and Canada, discussed above, were exacerbated by climate change, fires in the Amazon in 2019 were set intentionally as part of land clearing for cattle ranching and farming. Rather than being driven by climate change, the fires in Brazil contribute to it.

4.3.1 Forest fires, and their relationship to climate change

Brazil is home to around 60% of the Amazon forest, the largest rainforest on Earth.⁽⁷²⁾ An area known as the Deforestation arc in Brazil is the region where the agricultural frontier advances towards the rainforest and where the highest rates of deforestation in the Amazon are found.⁽⁷³⁾ It goes from Southeast Pará to the West, crossing Mato Grosso, Rondônia and Acre.⁽⁷²⁾

Where the forest margin borders newly opened up areas (known as the 'edge effect') the combination of moisture loss, increased temperatures and drought creates conditions which may result in natural fires. However, there is only a 500 year risk of this happening — the vast majority of fires in the



PC: Bruno Kelly - Amazônia Real - 2020

Amazon are caused by human activity.⁽⁷⁴⁾

Approximately 27 million people live in the Amazon basin,⁽⁷⁵⁾ and some 10 million of these live in areas of poor air quality.⁽⁷⁶⁾ There are growing concerns that deforestation for cattle ranching and the subsequent use of fire to clear felled trees that are regarded as having little value, coupled with climate change, may lead to a tipping point where the Amazon system no longer supports forest, but degrades to dry tropical savanna.^(77,78) This would mean that the Amazon's carbon, stored in the trees and soil would be

released into the atmosphere, adding further to climate change.⁽⁷⁹⁾

According to Human Rights Watch, the rate of destruction of the Brazilian Amazon is gathering pace and is largely tolerated by the government.⁽⁸⁰⁾

In Brazil the health impacts of biomass burning — or forest fires — have been studied mainly in the Amazon basin.⁽⁸¹⁾ The Amazon forest is intricately linked with health and with climate change. The 2018 Lancet Countdown brief for Brazil finds that 'The health of the Brazilian people is tied to the status of the Amazon forest ecosystem.' It goes on to state that, 'Due to the Amazon's potential to act as a climate tipping point, this forest is of global significance for health'.⁽²⁷⁾

In the devastating fires of August 2019, health impacts in Porto Velho, the state capital of Rondônia included increased cases of respiratory problems among its residents, particularly among children. The World Health Organisation (WHO) warned that the forest fires were a threat to children, the elderly and those with pre-existing respiratory and cardiovascular conditions.⁽⁸²⁾

The number of children treated at the local Cosme e Damia hospital more than doubled between the first and second 10 days of August. 'The kids are affected the most. They're coughing a lot,' said Elane Diaz, a nurse in Porto Velho, 'They have problems breathing. I'm concerned because it affects their health'.⁽⁸³⁾

Many communities were evacuated but Indigenous people living in the rainforest were not, and remained

4.3.2 Evidence of health impacts and status of research to date

exposed to fire and air pollution. Meanwhile, vast swathes of ancient forests were lost, along with both the wildlife they supported and their invaluable carbon stores.

In 2020 the Instituto Socioambiental (ISA) carried out the first national study of the link between forest fires and Indigenous health and showed a 25% increase on average in hospitalisations of Indigenous people over 50-years-old, due to respiratory problems.⁽⁸⁴⁾ The concentration of PM_{2.5} exceeded WHO safe standards in 81% of 616 municipalities where air quality data were collected. PM_{2.5} levels were highest in Rondônia, north-central of Mato Grosso, south-west of Pará, southeast of Amazonas, region of Manaus and Roraima. In Novo Progresso (PA), PM_{2.5} was recorded at 570 µg/m³, some 23 times more than the WHO safe standard.⁽⁸⁵⁾ In Rondônia, PM_{2.5} was associated with 67.6% of hospitalisations of Indigenous people for respiratory problems in this age group. In Mato Grosso, there was an increase of 33.6% in hospitalisations of Indigenous people over 49-years-old in the period of burning compared to the previous three months.

The study concluded that 'long-term exposure to air pollution increases the vulnerability of Indigenous peoples to the most serious effects of COVID-19'. This is of particular concern as the death rate from Covid is 250% higher among Indigenous people than the national average.⁽⁸⁶⁾ This connection between air pollution and vulnerability to COVID-19 symptoms has been suggested by several other studies.^(87,88)

Biomass burning (the burning of trees during land clearing) mainly takes place during the Brazilian Amazon dry season from June to October, also known as the *queimadas* season. Atmospheric monitoring has been carried out in the region since 1992 by the Amazon Biosphere and Atmosphere Large Scale Experiment of the University of São Paulo. The first national survey on forest fires was carried out in 1983 when 227 fires were recorded.⁽⁸⁹⁾ Air quality standards in Brazil, established by the National Environment Council, set limits for PM₁₀ only, not PM_{2.5}. The Brazilian daily average guideline is set at 60 µg/m³ which is higher than the WHO daily average of 50 µg/m³ for PM₁₀. Levels of particulate matter usually exceed the WHO guidelines during the *queimadas* season.⁽⁸⁵⁾

'It is important to make it clear that



PC: Marizilda Cruppe - Amazônia Real - Amazon Watch - 2020

'At this time we are living in a very critical situation due to the Coronavirus. All health units are full, all full because of coronavirus. When the fire period begins we do not know how much capacity there will be for additional care for patients affected by the fire smoke.'

'Even before Covid, the availability of hospital services in the state of Rondônia was a critical issue. The city grew rapidly after the construction of two hydroelectric dams which drew in a lot of people. Hospitals have not kept pace with population growth and the combination of Covid and the next fire season is a real concern.'

'As a Nurse Union leader, I would like to urge the health secretary of the region to plan ahead for the return of smoke induced illnesses while health services continue to battle with the pandemic. Plans could include having a specific unit to treat respiratory diseases exacerbated by the fires.'⁽⁹⁰⁾

**Jerrimar Soares Montenegro, Nurse Union Affairs
Director in the Union of Nursing Professionals
(SINDERON), Rondonia,, Brazil**



most epidemiological studies that evaluate acute and chronic effects of PM¹⁰ on respiratory and cardiovascular diseases show a linear relationship between exposure and outcomes. This means that there is no safe level of concentration of this pollutant and that the effects are observed even at levels of concentration well below the adopted air quality standards'.⁽⁹¹⁾

These man-made fires can affect urban air quality when particulate matter, trace metals and greenhouse gases travel to urban areas.⁽³⁷⁾ In the Amazon, particles emitted by biomass burning remain in the atmosphere for at least a week and can be transported over long distances.⁽⁸¹⁾ This study found that most adverse effects found lagged by three, four, and five days, in part because of the pollutants staying in the atmosphere for long periods. Consequently,

pollutants originating from fires may not map with the location of the fires because smoke disperses vast distances from the source.

The majority of forest fire hotspots in the region are recorded in the Arc of Deforestation which lies from Para in the north to Mato Grosso in the south and the Brazil-Peru-Bolivia area in the southwest. Two areas, Alta Floresta and Tangará da Serra are priority areas for assessing the impacts of biomass burning from air pollution in the Brazilian Amazon.^(81,92)

Human Rights Watch reported that 'Environmental officials are struggling with the logistical difficulties of training and deploying firefighting personnel amidst the COVID-19 pandemic'.⁽⁸⁰⁾ Their research highlighted that while plans to implement air quality monitoring have been in place for three decades through the National Environmental Council (CONAMA) which represents government, the private sector and civil society, these have not been widely implemented.

Several studies from cities in the Amazon basin have shown that particulate matter from forest burning is associated with low birth weight,⁽³⁷⁾ increased risk of respiratory disease among children and elderly people and higher rates of hospital admissions.

^(85,93-95) Studies of children and older people in the Arc of Deforestation have shown increases in outpatient and emergency room visits as well as hospital admis-

sions, alongside decreases in peak expiratory flow (PEF) used to measure lung function.⁽⁸¹⁾ Air pollution presents a major risk factor to children, because they are still developing physiologically and impacts may have consequences in adulthood,⁽⁸¹⁾ though the long-term impacts of wildfire smoke on children have thus far been understudied. In 2005, following a prolonged drought in the Amazon, more than 400,000 people were exposed to smoke from the fires with economic losses estimated at US\$ 50 million.⁽⁹⁶⁾

A time series analysis of patients in Rio Branco, Brazil showed that the number of hospital emergency visits increased with exposure to fine particulate matter. Of 2,922 patients treated, the most frequent clinical symptoms were: cough (79%), fever (51%), dyspnea (difficulty breathing) (39%), chest pain (15%), wheezing (8%) and irritation in the throat (4%).⁽⁹⁷⁾ Indigenous people in the Amazon are particularly vulnerable to the impacts of fire on health and also face the destruction of crops and medicinal plants.⁽⁸⁰⁾ The extent of forest burning has increased with government support for mineral extraction and the removal of protection for areas of Indigenous lands.⁽²⁷⁾

The need for air pollution monitoring within the Amazon basin has been highlighted, as computational modelling had to be relied on in the absence of data from local monitoring stations.⁽³⁷⁾ The same study noted the importance of other confounding

factors that could be associated with low birth weight, such as exposure to tobacco or use of wood stoves. Tobacco smoking remains a major public health issue in Brazil.

It was estimated that nearly three million people were exposed to harmful levels of PM_{2.5} during the 2019 fires.⁽⁸⁰⁾ Many people have limited access to health facilities so data on numbers of patients hospitalised in Brazil can only give an incomplete picture of the impact of the fires on health. Many more people will experience respiratory problems, but do not require hospitalisation.

A recent assessment of the public health benefits of preventing fires in the Amazon would avoid approximately 17,000 premature deaths due to the reduction in PM_{2.5} exposure across South America.⁽⁹⁸⁾

In an interview with Jerrimar Soares Montenegro, a nurse with SINDERON, the professional nurses association in the state of Rondônia, the burning period was identified as running from July/August to mid-November when the rains begin. When the period of burning begins, the city, Porto Velho, is shrouded in fog. In July and August respiratory diseases increase, especially among the elderly, patients with chronic lung disease and children with asthma.

4.3.3 Indigenous People living in the Amazon basin

Forest fires in the Amazon threaten Indigenous peoples' lives and livelihoods through the impacts of smoke on health, as well as the invasion of their territories through illegal deforestation, which damages crops, materials and medicines and land used for hunting and fishing.⁽⁸⁰⁾ The impacts of colonisation are severe and wide ranging. Indigenous resilience and survival stem from an interconnectedness with nature and there is a growing recognition that Indigenous knowledge systems may help address the twin climate and biodiversity emergencies.⁽⁹⁹⁾

Water sources may also be contaminated by ash from the fires. Indigenous people in the Brazilian Amazon are especially vulnerable to smoke because there is a high prevalence of preventable respiratory diseases such as tuberculosis in the community compared to the national average.⁽¹⁰⁰⁾

There is little published material about how Indigenous people in the Brazilian Amazon access information on the health impacts of smoke and how to reduce their exposure.

In an interview with Marcelo Salazar of 'Health in Harmony' the importance of mobile phone apps such as WhatsApp was emphasized because the audio message function enables people with low literacy levels to communicate quickly and at low cost.

Dr Fabio Tozzi, a vascular surgeon originally in São Paulo, Brazil was interviewed in connection with the

project 'Health and Happiness', delivered by an NGO which provides healthcare to riverside villages and Indigenous communities. In general the communities live very close to the rivers. During the fires the whole sky was sometimes filled with smoke. In the 2018 fire season the airport was closed for a week because the dense smoke meant that it was not safe to land aircraft.

He reported that the fires intensified in each of the years from 2014 to 2017 and the smoke had a negative impact on people's health including increased levels of asthma, bronchitis and bronchiolitis. Children were particularly affected.

Dr Tozzi explained that it was difficult to collect data about health impacts because there are no registers for Indigenous people and smoke-related respiratory conditions. Other issues such as poor water quality and diseases that are more prevalent such as malaria and tuberculosis dominate health concerns. Dr Tozzi worked in 150 communities every month treating 30,000 people and had sufficient medicines to treat the communities even during the *queimadas*.

In 2019 the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) produced the first global-level assessment of its kind to include systematic review of Indigenous and local knowledge and practices in regards to biodiversity. The Global Assessment Report on Biodiversity and Ecosystem Services recommended inclusion of Indigenous and local knowledge alongside science as key knowledge systems for protecting natural systems and sustainability.⁽¹⁰¹⁾



PC: Sérgio Vale - Amazônia Real - 2020

'The Yanomami people are living in a crisis. Our health is precarious. In our villages it is more difficult to assist the population [with health needs] because there is no transport, there is no hospital nearby, there is no ambulance, there are no doctors.'

'Today the pollution is great: our rivers are bad, they are contaminated, the change and the deforestation of the Amazon, for example, the burning. In our village there are no wildfires, we know how to live within our environment. Because we talk to Mother Earth. We do not cut down trees without grace, do not cut down trees without a reason. We make our garden, we build our house, we ask for permission, how many more or less trees can we cut down. We know how to manage it. Mother Earth sustains the traditional people and we know how to connect with her.'

(102)

Dario Kopenawa
Vice President of Hutukara Yanomami
association, Brazil

4.4 Wildfires in other countries

The wildfires of Canada and Australia, and Brazil's forest burning are just three examples of the growing threat of landscape fires around the world. Recent wildfires were also recorded in the following countries:

Bolivia

On September 15, 2020 the Bolivian interim president, Jeanine Áñez declared an emergency due to the forest fires in the east of the country that threatened the Chiquitania area and the Noel Kempff Mercado Park, one of the main Bolivian natural reserves.⁽¹⁰³⁾ There were 21 active fires close to the border with Brazil which affected 393,648 hectares. In 2019, more than 2.5 million hectares were damaged during the Amazon fires, which were considered one of the biggest ecological disasters in the country's recent history.

Paraguay

Devastating wildfires also broke out in Paraguay in 2020 with 5,231 individual fires burning across the country. Most were concentrated in the west of the country, but thick yellow smoke reached as far as the capital, Asunción.⁽¹⁰⁴⁾

Siberia

Abnormally high temperatures in eastern Siberia drove intense wildfires in the region in 2020 which destroyed 19 million hectares.⁽⁷⁾ Smoke from Siberian wildfires affected air quality in Alaska and cities as far away as Seattle.

'We're literally tasting the environmental crisis: we're breathing smoke.'

Guillermo Achucarro, climate policy researcher at Base-IS research centre in Asunción⁽¹⁰⁴⁾

US

Thousands of lightning strikes triggered hundreds of fires across California, Washington and Oregon in 2020.⁽¹⁰⁵⁻¹⁰⁷⁾ A state of emergency was declared because densely populated areas were threatened. The 2020 fires followed on from unprecedented fires in 2017 and 2018, including the fires that destroyed the township of Paradise, California.

California experienced a series of major forest fires of increasing frequency and severity in the 1980s, 1990s and 2000s. In 2007, losses were estimated at US\$ 1 billion with the destruction of 1,500 homes, affecting a population of around one million people.⁽¹⁰⁸⁾ Since then there have been what have been described as unprecedented fires in 2017, 2018 and 2020 meaning that extreme wildfires are becoming an almost annual event.

South East Asia

Landscape fires and haze are an annual problem in Indonesia as forests are deliberately cleared for commercial agriculture, primarily oil palms, with the haze affecting nearby countries such as Thailand and Singapore.⁽¹⁰⁹⁾ The 2020 dry season was milder than the 2019 fire season,



which was the worst since 2015, when 1.65 million hectares of forest area were burned. The estimated cost to the economy was US\$ 5.2 billion, 0.5% of Indonesia's GDP.

In Singapore, during the 2020 fire season, there was a 30% increase in the demand for medical care for diseases related to smoke exposure. Time series analyses showed associations between health outcome and exposure to fires.⁽¹¹⁰⁾ For each 10 $\mu\text{g}/\text{m}^3$ increment of PM_{10} from 50 $\mu\text{g}/\text{m}^3$ to 150 $\mu\text{g}/\text{m}^3$ there were 12% increases in visits for diseases of the upper

respiratory tract, 19% for asthma and 26% for rhinitis. No associations were found for hospitalisations and mortality.

5.

Stories from the Smoke:

Themes





For the purposes of this report interviews were carried out with health professionals and Indigenous people in Canada, Australia and Brazil who experienced the forest fire episodes described in this report.

A number of themes emerged from the interviews from each of the countries, most of which mirror the discussion in academic papers, policy reports and media coverage of wildfire events and planned forest fires reviewed here. In connection with the Australian 2019/2020 fires, the unprecedented ferocity of the fire and smoke persisting for days and weeks, which was outside of previous experience, were described by all those interviewed. Immediate impacts which were more intense than anticipated included having to reach safety through blackened skies, burning embers, and poor air quality. A lack of preparedness for fire and particularly smoke pollution was noted. Short term health impacts included cough, shortness of breath, and corneal damage from the smoke. In Australia, the need for recognition and implementation of Indigenous forest management — an alternative or complementary approach to Western forest management methods — was raised (see section 6).

Additional issues that emerged from the interviews included a concern that the long-term health impacts of such prolonged exposure are unknown and could include fibrosis of the lung (thickening or scarring) and impacts on birth outcomes.

Forest fire in all three case studies exposed inequalities particularly for Indigenous people living in and/or managing forest areas.



'Then the power went out. That lasted for four days, the only way we could find out what was going on was to sit in the car and listen to the ABC Radio.'

'The Country Club didn't really know that it was going to be the evacuation point. But you literally couldn't walk and couldn't breathe out there. There was no way you could even see the end of the driveway. It's hot with embers. There's no way you could be out in it without protective gear. Nobody's told anybody this — we just thought we'd be able to walk down to the club.'

(11)

Dr Joanne Walker DPH
(Dr Public Health / Research), New South Wales, Australia

The impact on water quality of ash from the smoke and the fire retardant dropped from planes and helicopters was also described. In Australia these impacts were ongoing 12 months later. There was a clear impact on tourism in areas that are visited for their high quality natural environment in Australia and Canada. In addition, an issue emerged from the Australian interviews that one interviewer described as 'metropolitan narcissism', which reflected a tension between gratitude for assistance mixed with discomfort associated with the arrival of city-based mental health support professionals — while the support was needed, it was hard for some local people to develop trust with strangers from the cities who had not experienced the fires.

The need to develop and keep fire plans updated and communicated to residents was emphasised. The added risk of having to manage social distancing for COVID-19 during fire episodes and the need to evacuate was noted, with recognition that evacuation of residents to community centres requires additional planning.

6.

Indigenous Fire Practices

It may seem counterintuitive to fight fire with fire given the devastation that uncontrolled wildfires leave in their wake. The fires discussed in the case studies above burned hot and fast, and have left lasting damage on the landscapes and serious impacts on communities. However, fire is used in carefully controlled ways by Indigenous communities around the world in forested areas to suppress undergrowth in order to discourage big fires and to encourage new plant growth, attracting wildlife and bush food.⁽¹¹²⁻¹¹⁴⁾ An interview was conducted with Noel Webster Indigenous fire stick practitioner from New South Wales, Australia to get an understanding of what are known as 'cultural burns'. This interview is summarised below.

In cultural burns, fires are controlled and move at walking pace. They do not have the ferocity of wildfires, nor of hazard reduction burns, and as such do not damage the soil microflora and fauna, in what is described as a cool burn. In addition, these gentle, managed fires do not dry the land out, which may happen after hazard reduction burns or bushfires because they are so hot and intense and last too long.

In Australia, Indigenous knowledge has been passed down through millenia and is shared with the community through storytelling and spending time in Country (the name for the land/Earth) doing cultural burns and introducing young people to these techniques.

The approach is one of prevention and connectedness. Through understanding the ecological connections of Country, the approach is land management which reduces fire risk and intensity of fire and supports new growth.

Many cultural sites were lost during the 2019/2020 fires. There was a frustration that once the bushfires were out Indigenous people were left to clear up and restore what

'What we're saying is look after Country properly. We don't have to be a firefighter and we're not firefighters. We want people to be fire practitioners, to start caring for the land and apply the right fire for the right Country type. But they don't do that, they got one fire methodology. And that applies right across the landscape.'

'Our aspiration is to work with the fire agencies and change their fire practice, use Indigenous knowledge systems to start looking after Country when it comes to their fire practice. Yeah, that's our aspiration, to change it.' (69)

Noel Webster Indigenous fire stick practitioner New South Wales, Australia

they could. A tension exists between the heroics of putting out fires and an Indigenous response which respects and is guided by Country, and then people and property.

The 2020 Royal Commission included two key recommendations about the use of cultural burns. These included the sharing of knowledge and understanding about cultural burns and further investigation into how cultural burning could be used to improve forest and fire management in Australia.

Following the fires there has been a growing interest in the use of cultural burns as part of Australian forest management techniques. It is important to be aware of the risk of cultural appropriation, however. Any widespread ramping up of the use of cultural burning must be done in coordination and collaboration with Indigenous peoples and their understanding of Country.

Box 6: Royal Commission into National Natural Disaster Management Arrangements (also known as the Bushfire Royal Commission): Indigenous land management⁽⁵⁾

‘Indigenous land management aims to protect, maintain, heal and enhance healthy and ecologically diverse ecosystems, productive landscapes and other cultural values. It is not solely directed to hazard reduction. It is an example of how local knowledge has successfully informed land management for tens of thousands of years. Today, Indigenous land management maintains its traditional and cultural importance, while also leveraging technologies such as helicopters and satellites. There is growing recognition of the value of Indigenous land and fire management practices as a way to mitigate the effects of bushfires. All governments should work with Traditional Owners to explore the relationship between Indigenous land management and natural disaster resilience. Governments and land managers should further explore the opportunities for Indigenous land and fire management in land management strategies’.

The Royal Commission recommendations:
‘Indigenous land management is an example of how local knowledge has successfully informed land management, and it has done so for tens of thousands of years. It draws on a deep knowledge of Australia’s landscapes. It is based on cultural understandings of Country, is tailored to specific places, and engages local people in development and implementation. Partly for these reasons, Indigenous land management differs widely across Australia’

‘There is a growing recognition of the value of Indigenous land and fire management practices as a way to mitigate the effects of bushfires and improve disaster resilience. Governments should continue to engage with Traditional Owners to explore the relationship between Indigenous land management and disaster resilience’

7.

Conclusions and

Recommendations





The WHO has declared climate change a public health emergency. A devastating example of this complex unfolding emergency are the forest fires that have raged around the world, even in the Arctic circle.⁽¹¹⁵⁾ While the flames grab attention, the long term impacts of smoke and air pollution do not.

Fires have long been a part of the environments humans inhabit, but they are getting bigger and more intense due to climate change, and due to human land use practices that are driving and contributing to climate change. Forest fires that burn for longer and with greater intensity are producing smoke and air pollution which reaches large populations in distant cities and disproportionately affect the most vulnerable, including those with respiratory conditions and the elderly. This will likely get worse in the coming years and intensify the harms to health in our populations.

Systematic monitoring and reduction of air pollution from forest fires is needed, and must go hand-in-hand with reducing the causes of forest fires and an improved public health response. Ultimately global leaders must step up and limit the warming of the planet through rapid climate action.

Forest protection and management Approaches to forest protection and management must change to ones that support fire prevention, rather than ones that rely on heroic emergency rescues. In Brazil a significant population is at risk from long periods of forest burning on an annual basis, producing ongoing smoke exposure. This could be stopped immediately with a moratorium on deforestation and the political commitment to protect the Amazon forest and the people who live within it. In Australia and Canada, bigger, more intense fires are driven by both climate change and poor forest management. The knowledge and skills that Indigenous communities hold could help develop more sustainable approaches to forest management in a warmer world.

'We need to start to work hard on our forecasting, on our scenario planning and on using imagination, otherwise we won't be adequately prepared.'⁽¹⁾

Dr Arnagretta Hunter
Cardiologist, ANU, Canberra, Australia

Health risk mitigation and adaptation

The health risks of fire smoke pollution should be factored into managing and reducing forest fires. This will require collaboration between public health departments, health practitioners, environmental departments and Indigenous agencies, both in the immediate evacuation planning, and monitoring and responding to drifting smoke causing air pollution in more distant population centres, including building public health awareness and protecting the most vulnerable. Anticipating worsening smoke seasons in the decades to come, housing retrofits and new builds should be designed with improved ventilation systems.

Health impact data collection and research

The substantial health burden associated with the indirect effects of smoke from wildfires and its impact on health services is beginning to be felt and assessed. Short term health impacts are well documented but long term health impacts of prolonged periods of forest fire smoke exposure remain unclear. In the process of completing this report it was evident how difficult it is to access health data, most of which is not in the public domain for reasons of confidentiality. However, this is a significant barrier to increasing understanding of the linkages between health and climate change. In this context the development of the new European Observatory on Climate and Health is welcome.⁽¹¹⁶⁾ Given populations are exposed to forest fire smoke in Brazil on an annual basis, research on health impacts in Brazil could help inform other countries around the world that are experiencing an increase in wildfires and smoke.



'People don't like to think about the decades ahead — we wouldn't be in the current climate crisis if they did. In my work, I repeatedly see that smoke arrives, everybody gets worked up about it, then it dissipates and everyone forgets about it. If the next year is not a bad wildfire year, wishful thinking sets in and the previous severe season is remembered as an anomaly. However, this problem is with us for decades and it's going to have long-term health consequences.' (39)

Dr Sarah Henderson
Scientific Director, Environmental Health Services,
British Columbia Centre for Disease Control (BC-
CDC) Associate Professor, School of Population
and Public Health, University of British Columbia

Global Action In the last year the COVID-19 pandemic has realised a long-feared threat of a new infectious agent spreading disease around the world. The devastation caused during the North American and Australia fire seasons that preceded the pandemic should also be recognised as another stark warning of how human health harms spread far beyond the source of the initial crisis.

To help us mitigate the significant health risks of forest fires and the smoke-related air pollution they cause, we must increase our understanding of the long term health impacts of prolonged exposure to smoke; the interconnections between forest destruction, fires, and climate change; and the climate change impacts that are contributing to worsening of forest fires.

This year, the world's governments will meet to consider the inter-related planetary threats of biodiversity loss and climate change at the CBD COP15 in October and at the UNFCCC COP26 in November. They must see the stark evidence of far-reaching health harms as yet another compelling

reason to close the gap between the level of action that is needed to address health and climate change, and the present woefully insufficient commitments and policies.

The 'Nationally Determined Contributions' (NDCs) being developed and submitted in the lead up to COP26 must both align with the climate targets set out by the Paris Agreement to limit warming to well below 2C, aiming for 1.5C, and address the related opportunities for health benefits from climate solutions. The trillions of dollars committed to COVID-19 economic stimulus packages present governments with an unprecedented opportunity to apply the resources necessary to achieve a healthy and green recovery.

2021 provides a unique opportunity to respond to the unfolding public health emergency of climate change, including the increasing threat of wildfires and forest fires. We fit smoke alarms in our homes as a front line defence against fire. The planet's smoke alarm is getting louder and louder. It is time to respond.

8. References

1. Hunter A. Forest fire smoke and health [unpublished interview]. 2020.
2. Howard C. Forest fire smoke and health [unpublished interview]. 2021.
3. Watts. Amazon rainforest fires: global leaders urged to divert Brazil from “suicide” path. the Guardian [Internet]. 2019 Aug 23 [cited 2021 Jun 10]; Available from: <http://www.theguardian.com/environment/2019/aug/23/amazon-fires-global-leaders-urged-divert-brazil-suicide-path>
4. Hitch G. Black Summer bushfire smoke killed nearly 450 people, royal commission hears [Internet]. 2020 [cited 2021 Mar 11]. Available from: <https://www.abc.net.au/news/2020-05-26/bushfire-royal-commission-hearings-smoke-killed-445-people/12286094>
5. Binskin M, Bennett A, Macintosh A. Royal Commission into National Natural Disaster Arrangements Report. Commonwealth of Australia; 2020. 594 p.
6. Borchers Arriagada N, Palmer AJ, Bowman DM, Morgan GG, Jalaludin BB, Johnston FH. Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. *Med J Aust.* 2020;213(6):282–3.
7. Hirschlag A. The long distance harm done by wildfires. 2020.
8. Horsley JA, Broome RA, Johnston FH, Cope M, Morgan GG. Health burden associated with fire smoke in Sydney, 2001–2013. *Med J Aust.* 2018 Apr 16;208(7):309–10.
9. Bowman DMJS, Kolden CA, Abatzoglou JT, Johnston FH, van der Werf GR, Flannigan M. Vegetation fires in the Anthropocene. *Nat Rev Earth Environ.* 2020 Oct 1;1(10):500–15.
10. Alencar A, Moutinho P, Arruda V, Silvério D. IPAM Amazônia | The Amazon in Flames: Fire and deforestation in 2019 and what’s to come in 2020 [Internet]. 2020 [cited 2021 Mar 29]. Available from: <https://ipam.org.br/wp-content/uploads/2020/04/NT3-Fire-2019.pdf>
11. Cameron PA, Mitra B, Fitzgerald M, Scheinkestel CD, Stripp A, Batey C, et al. Black Saturday: the immediate impact of the February 2009 bushfires in Victoria, Australia. *Med J Aust.* 2009 Jul 6;191(1):11–6.
12. Dodd W, Scott P, Howard C, Scott C, Rose C, Cunsolo A, et al. Lived experience of a record wildfire season in the Northwest Territories, Canada. *Can J Public Health.* 2018 Jun;109(3):327–37.
13. Khaykin S, Legras B, Bucci S, Sellitto P, Isaksen I, Tencé F, et al. The 2019/20 Australian wildfires generated a persistent smoke-charged vortex rising up to 35 km altitude. *Commun Earth Environ.* 2020 Sep 21;1(1):1–12.
14. Seftor C, Gutro R. NASA Animates World Path of Smoke and Aerosols from Australian Fires. 2020.
15. Varghese S. Climate change has introduced a new word to the lexicon: pyrocumulonimbus. 2020.
16. Carpani J, Rudgard O. Orange skies across UK caused by California wildfires burning 5,000 miles away. The Telegraph [Internet]. 2020 Sep 11 [cited 2021 Jun 10]; Available from: <https://www.telegraph.co.uk/news/2020/09/11/california-wildfires-cause-orange-glow-uk-sky/>
17. Kollanus V, Tiittanen P, Niemi JV, Lanki T. Effects of long-range transported air pollution from vegetation fires on daily mortality and hospital admissions in the Helsinki metropolitan area, Finland. *Environ Res.* 2016 Nov;151:351–8.
18. Harvey, ClimateWire C. Here’s What We Know about Wildfires and Climate Change [Internet]. Scientific American. [cited 2021 Mar 11]. Available from: <https://www.scientificamerican.com/article/heres-what-we-know-about-wildfires-and-climate-change/>

19. Johnston FH. Burning to reduce fuels: the benefits and risks of a public health protection strategy. *Med J Aust.* 2020 Sep 21;213(6):246-248.e1.
20. Wong JC. Powerful winds spark new blazes in California's year-round fire "season" [Internet]. *the Guardian.* 2021 [cited 2021 Mar 11]. Available from: <http://www.theguardian.com/us-news/2021/jan/19/california-fire-climate-crisis-high-winds>
21. Black C, Gerriets JE, Fontaine JH, Harper RW, Kenyon NJ, Tablin F, et al. Early Life Wildfire Smoke Exposure Is Associated with Immune Dysregulation and Lung Function Decrements in Adolescence. *Am J Respir Cell Mol Biol.* 2017 May;56(5):657-66.
22. Tan-Soo J-S, Pattanayak SK. Seeking natural capital projects: Forest fires, haze, and early-life exposure in Indonesia. *Proc Natl Acad Sci U S A.* 2019 Mar 19;116(12):5239-45.
23. Lem, Melissa. Forest fire smoke and health [unpublished interview]. 2020.
24. Johnston FH, Purdie S, Jalaludin B, Martin KL, Henderson SB, Morgan GG. Air pollution events from forest fires and emergency department attendances in Sydney, Australia 1996-2007: a case-crossover analysis. *Environ Health.* 2014 Dec 10;13(1):105.
25. Urbanski SP, Hao WM, Baker S. Chemical composition of wildland fire emissions [Internet]. In: Bytnerowicz, A.; Arbaugh, M.; Riebau, A.; Andersen, C., eds. *Developments in environmental science, Volume 8: Wildland fires and air pollution.* The Netherlands: Elsevier: 79-107. 2009 p. 79-107. Available from: <https://www.fs.usda.gov/treesearch/pubs/33764>
26. Xu R, Yu P, Abramson MJ, Johnston FH, Samet JM, Bell ML, et al. Wildfires, Global Climate Change, and Human Health. *N Engl J Med.* 2020;383(22):2173-81.
27. Floss M, Barros E. *Lancet Countdown 2018: Briefing for Brazilian Policy Makers.* The Lancet. 2018;
28. Johnston F. Health impacts of bushfire smoke.
29. Vardoulakis S, Jalaludin BB, Morgan GG, Hanigan IC, Johnston FH. Bushfire smoke: urgent need for a national health protection strategy. *Med J Aust.* 2020;212(8):349-353.e1.
30. Henderson SB, Michael Brauer, Ying C. MacNab, Susan M. Kennedy. Three Measures of Forest Fire Smoke Exposure and Their Associations with Respiratory and Cardiovascular Health Outcomes in a Population-Based Cohort. *Environ Health Perspect.* 2011;119(9):1266-71.
31. Johnston FH, Sarah B. Henderson, Yang Chen, James T. Randerson, Miriam Marlier, Ruth S. DeFries, et al. Estimated Global Mortality Attributable to Smoke from Landscape Fires. *Environ Health Perspect.* 2012;120(5):695-701.
32. Borchers Arriagada N, Horsley JA, Palmer AJ, Morgan GG, Tham R, Johnston FH. Association between fire smoke fine particulate matter and asthma-related outcomes: Systematic review and meta-analysis. *Env Res.* 2019 Dec;179(Pt A):108777.
33. Melody SM, Johnston FH. Coal mine fires and human health: What do we know? *Int J Coal Geol.* 2015 Dec 1;152:1-14.
34. Payam Dadvand, Jennifer Parker, Michelle L. Bell, Matteo Bonzini, Michael Brauer, Lyndsey A. Darrow, et al. Maternal Exposure to Particulate Air Pollution and Term Birth Weight: A Multi-Country Evaluation of Effect and Heterogeneity. *Environ Health Perspect.* 2013;121(3):267-373.
35. Johnston FH, Salimi F, Williamson GJ, Henderson SB, Yao J, Dennekamp M, et al. Ambient Particulate Matter and Paramedic Assessments of Acute Diabetic, Cardiovascular, and Respiratory Conditions. *Epidemiol Camb Mass.* 2019 Jan;30(1):11-9.

36. Jiayun Yao, Michael Brauer, Julie Wei, Kimberlyn M. McGrail, Fay H. Johnston, Sarah B. Henderson. Sub-Daily Exposure to Fine Particulate Matter and Ambulance Dispatches during Wildfire Seasons: A Case-Crossover Study in British Columbia, Canada. *Environ Health Perspect.* 2020;128(6):067006.
37. Cândido da Silva AM, Moi GP, Mattos IE, Hacon Sde S. Low birth weight at term and the presence of fine particulate matter and carbon monoxide in the Brazilian Amazon: a population-based retrospective cohort study. *BMC Pregnancy Childbirth.* 2014 Sep 6;14:309.
38. Howard C, Rose C, Dodd W, Kohle K, Scott C, Scott P, et al. SOS! Summer of Smoke: a retrospective cohort study examining the cardiorespiratory impacts of a severe and prolonged wildfire season in Canada's high subarctic. *BMJ Open.* 2021 Feb 1;11(2):e037029.
39. Henderson A. Forest fire smoke and health [unpublished interview]. 2020.
40. NSW Health. NSW Health again issues warning on bushfire smoke. 8 January 2020. Press Release. 2020.
41. Elliott CT, Henderson SB, Wan V. Time series analysis of fine particulate matter and asthma reliever dispensations in populations affected by forest fires. *Env Health.* 2013 Jan 28;12:11.
42. Turco M, Rosa-Cánovas JJ, Bedia J, Jerez S, Montávez JP, Llasat MC, et al. Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. *Nat Commun.* 2018 Oct 2;9(1):3821.
43. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Switzerland: IPCC; 2014 p. 151.
44. Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., — O. Pörtner, H., Roberts, D. C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vuas, P., Huntley, E., Kissick, K., Belkacemi, M., Malley, J. (eds.). IPCC, 2019: Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [Internet]. [cited 2021 Mar 28]. Available from: <https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/>
45. Sun Q, Miao C, Hanel M, Borthwick AGL, Duan Q, Ji D, et al. Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environ Int.* 2019 Jul 1;128:125–36.
46. Stone S. Wildfire Smoke: A guide for public health officials [Internet]. California Air Resources Board; 2019 Aug p. 88. Report No.: EPA-452/R-19-901. Available from: <https://www.airnow.gov/sites/default/files/2021-05/wildfire-smoke-guide-revised-2019.pdf>
47. Association of BC Forest Professionals. Wildfire in BC [Internet]. Association of BC Forest Professionals. [cited 2021 May 20]. Available from: <https://abcfp.ca/web/ABCFP/ABCFP/Media/Wildfire-in-BC.aspx>
48. Australian Institute of Health, Welfare. Australian bushfires 2019–20: exploring the short-term health impacts. Canberra: AIHW; 2020.
49. ISA — Instituto Socioambiental. Fumaça de incêndios impulsiona interações de indígenas, mostra estudo [Internet]. ISA — Instituto Socioambiental. 2020 [cited 2021 Mar 11]. Available from: <https://www.socioambiental.org/pt-br/noticias-socioambientais/fumaca-de-incendios-impulsiona-internacoes-de-indigenas-mostra-estudo>

50. Albuquerque Sant'Anna, A, Rocha R. Health Impacts of Deforestation-Related Fires in the Brazilian Amazon [Internet]. IEPS. [cited 2021 Mar 28]. Available from: <https://ieps.org.br/pesquisas/impactos-dos-incendios-relacionados-ao-desmatamento-na-amazonia-brasileira-sobre-saude/>
51. Johnston FH, Borchers-Arriagada N, Morgan GG, Jalaludin B, Palmer AJ, Williamson GJ, et al. Unprecedented health costs of smoke-related PM_{2.5} from the 2019–20 Australian megafires. *Nat Sustain*. 2021 Jan 1;4(1):42–7.
52. Albuquerque Sant'Anna André, Rocha R. Health Impacts of Deforestation-Related Fires in the Brazilian Amazon [Internet]. IEPS. [cited 2021 Mar 27]. Available from: <https://ieps.org.br/pesquisas/impactos-dos-incendios-relacionados-ao-desmatamento-na-amazonia-brasileira-sobre-saude/>
53. Goldman M, Flynn A, Cartwright A, Bell R, Davis S, Bui D. ASTHMA AUSTRALIA BUSHFIRE SMOKE IMPACT SURVEY 2019–2020. :29.
54. Government of Canada. Canada's Changing Climate Ottawa, Ontario, 2019. 2019.
55. Wotton M, Nock C, Flannigan M. Forest fire occurrence and climate change in Canada. *Int J Wildland Fire*. 2010 01;19:253–71.
56. Christianson A. Wildland Fire Evacuations in Canada. *Nat Resour Can*. 2017;
57. Howard C, Buse C, Rose C, MacNeill A, Parkes M. The Lancet Countdown on Health and Climate Change Policy brief for Canada. 2019.
58. B.C. year in review 2017: wildfires devastate the province like never before [Internet]. CKNW. [cited 2021 May 20]. Available from: <https://globalnews.ca/news/3921710/b-c-year-in-review-2017-wildfires/>
59. Sep 30 DH· TCP· P, September 30 2018 1:09 PM PT | Last Updated:, 2018. Back-to-back summers of smoke and fire stoke B.C. tourism industry fears | CBC News [Internet]. CBC. 2018 [cited 2021 May 20]. Available from: <https://www.cbc.ca/news/canada/british-columbia/back-to-back-summers-of-smoke-and-fire-stoke-b-c-tourism-industry-fears-1.4844731>
60. BC Wildfire Service. Wildfire Season Summary – Province of British Columbia [Internet]. British Columbia. Province of British Columbia; [cited 2021 Jun 11]. Available from: <https://www2.gov.bc.ca/gov/content/safety/wildfire-status/about-bcws/wildfire-history/wildfire-season-summary>
61. Zanobetti A, Dominici F, Wang Y, Schwartz JD. A national case-crossover analysis of the short-term effect of PM_{2.5} on hospitalizations and mortality in subjects with diabetes and neurological disorders. *Environ Health Glob Access Sci Source*. 2014 May 22;13(1):38.
62. Bowe B, Xie Y, Li T, Yan Y, Xian H, Al-Aly Z. The 2016 global and national burden of diabetes mellitus attributable to PM_{2.5} air pollution. *Lancet Planet Health*. 2018 Jul;2(7):e301–12.
63. Australian Institute of Health, Welfare. Australia's health 2020: data insights. Canberra: AIHW; 2020.
64. Johnston FH, Hanigan IC, Henderson SB, Morgan GG, Portner T, Williamson GJ, et al. Creating an integrated historical record of extreme particulate air pollution events in Australian cities from 1994 to 2007. *J Air Waste Manag Assoc*. 2011 Apr;61(4):390–8.
65. Zhang Y, Beggs P, McGushin A, Bambrick H, Trueck S, Hanigan I, et al. The 2020 special report of the MJA–Lancet Countdown on health and climate change: lessons learnt from Australia's "Black Summer." *Med J Aust*. 2020 Dec 1;213:490–492.e10.
66. Clifford J, Henderson A, Jambor C. Bushfire royal commission told health policy reforms "on ice" due to COVID-19. 2020.
67. Kotsirilos, Vicki. Forest fire smoke and health [unpublished interview]. 2020.

68. Black C, Tesfaigzi Y, Bassein JA, Miller LA. Wildfire smoke exposure and human health: Significant gaps in research for a growing public health issue. *Env Toxicol Pharmacol*. 2017 Oct;55:186–95.
69. Webster N. Indigenous fire management practices and Australian bushfires [unpublished interview]. 2020.
70. Emergency Leaders for Climate Action. Australian Bushfire and Climate Plan. 2020 p. 60. Report No.: 978-1-922404-04-6.
71. Souza AA, Oviedo A, Santos TM. Impactos na qualidade do ar e saúde humana relacionados ao desmatamento e queimadas na Amazônia Legal brasileira. *Inst Socioambiental*. 2020;
72. Veiga JB, Tourrand JF, Pocard-Chapuis R, Pickety MJ. Cattle ranching in the Amazon rainforest [Internet]. [cited 2021 May 20]. Available from: <http://www.fao.org/3/xii/0568-b1.htm>
73. Deforestation Patterns in the Amazon [Internet]. NASA Earth Observatory; 2004 [cited 2021 May 20]. Available from: <https://earthobservatory.nasa.gov/images/4385/deforestation-patterns-in-the-amazon>
74. Alencar A, Moutinho P, Arruda V, Silvério D. FIRE AND DEFORESTATION IN 2019 – AND WHAT'S TO COME IN 2020. 2020;14.
75. SUDAM. Boletim Amazônia. Superintendência do desenvolvimento da Amazônia; 2016 p. 152.
76. de Oliveira Alves N, Vessoni AT, Quinet A, Fortunato RS, Kajitani GS, Peixoto MS, et al. Biomass burning in the Amazon region causes DNA damage and cell death in human lung cells. *Sci Rep*. 2017 Sep 7;7(1):10937.
77. Lewis SL, Brando PM, Phillips OL, van der Heijden GM, Nepstad D. The 2010 Amazon drought. *Science*. 2011 Feb 4;331(6017):554.
78. Lovejoy TE, Nobre C. Amazon Tipping Point. *Sci Adv*. 2018 Feb 1;4(2):eaat2340.
79. Viana V. Health Climate Justice and Deforestation in the Amazon. In: Al-Delaimy WK, Ramanathan V, Sánchez Sorondo M, editors. *Health of People, Health of Planet and Our Responsibility: Climate Change, Air Pollution and Health* [Internet]. Cham: Springer International Publishing; 2020 [cited 2021 May 20]. p. 165–74. Available from: https://doi.org/10.1007/978-3-030-31125-4_13
80. Human Rights Watch. “The Air Is Unbearable” Health Impacts of Deforestation-Related Fires in the Brazilian Amazon. 2020.
81. Jacobson L da SV, Hacon S de S, Castro HA de, Ignotti E, Artaxo P, Saldiva PHN, et al. Acute Effects of Particulate Matter and Black Carbon from Seasonal Fires on Peak Expiratory Flow of Schoolchildren in the Brazilian Amazon. *PLOS ONE*. 2014;9(8):e104177.
82. Nebehay S. Amazon fires pose health risks to children: WHO. Reuters [Internet]. 2019 Aug 30 [cited 2021 May 20]; Available from: <https://www.reuters.com/article/us-brazil-environment-wildfire-who-idINKCN1VK1FM>
83. Health crisis as Amazon fires burn out of control [Internet]. The London Economic. 2019 [cited 2021 May 20]. Available from: <https://www.thelondoneconomic.com/news/world-news/health-crisis-as-amazon-fires-burn-out-of-control-158194/>
84. Fumaça de incêndios impulsiona internações de indígenas, mostra estudo [Internet]. ISA — Instituto Socioambiental. [cited 2021 Mar 11]. Available from: <https://www.socioambiental.org/pt-br/noticias-socioambientais/fumaca-de-incendios-impulsiona-internacoes-de-indigenas-mostra-estudo>
85. WHO. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide : global update 2005 : summary of risk assessment. World Health Organization; 2006.

86. Zuker F. Indigenous land intrusions help drive higher virus death toll in the Amazon. Reuters [Internet]. 2020 Aug 14 [cited 2021 May 20]; Available from: <https://www.reuters.com/article/us-health-coronavirus-brazil-amazon-anal-idUSKCN25A2BX>
87. Henderson SB. The COVID-19 Pandemic and Wildfire Smoke: Potentially Concomitant Disasters. *Am J Public Health*. 2020 Aug 1;110(8):1140–2.
88. Pozzer A, Dominici F, Haines A, Witt C, Münzel T, Lelieveld J. Regional and global contributions of air pollution to risk of death from COVID-19. *Cardiovasc Res*. 2020;116(14):2247–53.
89. Soares RV. Profile of forest fires in Brazil from 1984 to 1987. In: *Forest 1988*. 1988.
90. Soares, Jerrimar. Forest fire smoke and health [unpublished interview]. 2021.
91. Braga A, Pereira L, Procópio M, André P, Saldiva P. Association between air pollution and respiratory and cardiovascular diseases in Itabira, Minas Gerais State, Brazil. *Cad Saúde Pública Minist Saúde Fundação Oswaldo Cruz Esc Nac Saúde Pública*. 2007 01;23 Suppl 4:S570–8.
92. Ignotti E, Hacon S de S, Silva AMC, Junger WL, Castro H. Efeitos das queimadas na Amazônia: método de seleção dos municípios segundo indicadores de saúde. *Rev Bras Epidemiol*. 2007;10:453–64.
93. Ignotti E, Hacon Sde S, Junger WL, Mourão D, Longo K, Freitas S, et al. Air pollution and hospital admissions for respiratory diseases in the subequatorial Amazon: a time series approach. *Cad Saude Publica*. 2010 Apr;26(4):747–61.
94. Nunes KVR, Ignotti E, Hacon S de S. Circulatory disease mortality rates in the elderly and exposure to PM2.5 generated by biomass burning in the Brazilian Amazon in 2005. *Cad Saude Publica*. 2013;29:589–98.
95. Silva PR de S, Ignotti E, Oliveira BFA de, Junger WL, Morais F, Artaxo P, et al. High risk of respiratory diseases in children in the fire period in Western Amazon. *Rev Saúde Pública*. 2016;50.
96. Brown IF, Schroeder W, Setzer A, de Los Rios Maldonado M, Pantoja N, Duarte A, et al. Monitoring Fires in Southwestern Amazonia Rain Forests. *EOS Trans*. 2006 Jun 1;87:253.
97. Mascarenhas MDM, Vieira L, Lanzieri T, Leal AR, Duarte AF, Hatch D. [Anthropogenic air pollution and respiratory disease-related emergency room visits in Rio Branco, Brazil--September, 2005]. *J Bras Pneumol Publicacao Of Soc Bras Pneumol E Tisilogia*. 2008;
98. Butt EW, Conibear L, Reddington CL, Darbyshire EW, Morgan WT, Coe H, et al. Large air quality and human health impacts due to Amazon forest and vegetation fires. *Environ Res Commun*. 2020 Sep 16;2(9):095001.
99. Redvers N. The determinants of planetary health. *Lancet Planet Health*. 2021 Mar 1;5(3):e111–2.
100. PAHO. Tuberculosis in the Americas. 2018.
101. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services I. Summary for policymakers of the global assessment report on biodiversity and ecosystem services [Internet]. Zenodo; 2019 Nov [cited 2021 May 21]. Available from: <https://zenodo.org/record/3553579#.YKf4EahKg2w>
102. Kopenawa, Dario. Forest fire smoke and health [unpublished interview]. 2021.
103. Redacción EFEverde. Bolivia anuncia la declaración de emergencia por incendios forestales en el este. 2020.
104. Costa W. Wildfires tear through drought-racked Paraguay amid record heat. 2020.

105. U.S. Wildfire Map — Current Wildfires, Forest Fires, and Lightning Strikes in the United States | Fire, Weather & Avalanche Center [Internet]. FireWeatherAvalanche.org. [cited 2021 Mar 11]. Available from: <https://www.fireweatheravalanche.org/fire/>
106. McCormick E. What is California's wildfire smoke doing to our health? Scientists paint a bleak picture. 2020.
107. Dahl, Kristina. 5 of California's 6 Largest Fires on Record Are Burning Now: The Astonishing 2020 Wildfire Season in Context [Internet]. Union of Concerned Scientists. 2020 [cited 2021 Mar 11]. Available from: <https://blog.ucsusa.org/kristy-dahl/5-of-californias-6-largest-fires-on-record-are-burning-now-the-astonishing-2020-wildfire-season-in-context>
108. Keim ME. Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *Am J Prev Med*. 2008 Nov;35(5):508-16.
109. Jong HN. COVID-19 may worsen burning and haze as Indonesia enters dry season [Internet]. 2020 [cited 2021 Mar 11]. Available from: <https://news.mongabay.com/2020/07/covid-19-indonesia-forest-fire-haze-dry-season/>
110. Emmanuel SC. Impact to lung health of haze from forest fires: the Singapore experience. *Respirology*. 2000 Jun;5(2):175-82.
111. Walker, Joanne. Forest fire smoke and health [unpublished interview]. 2020.
112. Williamson GJ, Bowman DMJS, Price OF, Henderson SB, Johnston FH. A transdisciplinary approach to understanding the health effects of wildfire and prescribed fire smoke regimes. *Environ Res Lett*. 2016 Dec 1;11(12):125009.
113. Higgins I. Indigenous cultural burn a factor in helping save home from bushfire, as fire experts call for more investment [Internet]. 2020. Available from: <https://www.abc.net.au/news/2020-01-18/cultural-indigenous-burn-saves-home-in-bushfire-threat-area/11876972>
114. With wildfires on the rise, indigenous fire management is poised to make a comeback [Internet]. *Grist*. 2020 [cited 2021 May 21]. Available from: <https://grist.org/justice/with-wildfires-on-the-rise-indigenous-fire-management-is-poised-to-make-a-comeback/>
115. Witze A. The Arctic is burning like never before — and that's bad news for climate change. *Nature*. 2020 Sep 10;585(7825):336-7.
116. About the Observatory — European Climate and Health Observatory [Internet]. [cited 2021 Mar 11]. Available from: <https://climate-adapt.eea.europa.eu/observatory/About/about-the-observatory>