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Seasons of smoke and fire: preparing health systems for improved performance before, during, and after wildfires

Attila J Hertelendy*, Courtney Howard*, Cecilia Sorensen, Jamie Ranse, Ejemai Eboreime, Sarah Henderson, Jeffrey Tochkin, Gregory Ciottone



Increased frequency, intensity, and duration of wildfires are intensifying exposure to direct and smoke-related hazards in many areas, leading to evacuation and smoke-related effects on health and health systems that can affect regions extending over thousands of kilometres. Effective preparation and response are currently hampered by inadequate training, continued siloing of disciplines, insufficient finance, and inadequate coordination between health systems and governance at municipal, regional, national, and international levels. This Review highlights the key health and health systems considerations before, during, and after wildfires, and outlines how a health system should respond to optimise population health outcomes now and into the future. The focus is on the implications of wildfires for air quality, mental health, and emergency management, with elements of international policy and finance also addressed. We discuss commonalities of existing climate-resilient health care and disaster management frameworks and integrate them into an approach that addresses issues of financing, leadership and governance, health workforce, health information systems, infrastructure, supply chain, technologies, community interaction and health-care delivery, before, during, and after a wildfire season. This Review is a practical briefing for leaders and health professionals facing severe wildfire seasons and a call to break down silos and join with other disciplines to proactively plan for and fund innovation and coordination in service of a healthier future.

Introduction

Recent years have seen wildfires pose threats to health and health systems on many continents.¹ Climate change has been linked to multiple conditions that favour more fire, including earlier and lessened snow melt, changing precipitation patterns, altered wind patterns, and increasing vapour pressure deficit, which is an indicator of atmospheric dryness.^{2,3} We are not at a new normal: wildfire risk is projected to continue to increase.¹ By the middle of the century, the number of days of exposure to very high or high wildfire risk is expected to increase by 11% in scenarios with and without greenhouse gas mitigation.¹ Near the end of the century a scenario with no further decrease in greenhouse gases will result in triple the increase in exposure as compared with a scenario compatible with keeping global surface temperature increase to less than 2°C.¹

The costs of wildfires are huge. The Horse River wildfire in the Canadian province of Alberta cost more than US\$3 billion dollars in damages and forced thousands of residents to evacuate, including a 100-bed hospital.⁴ In 2023, the Canadian Climate Institute used Health Canada's Air Quality Benefits Assessment Tool to estimate that the exposure of approximately 9 million people to smoke over five days in Ontario had a \$1·28 billion effect on health outcomes.⁵

Under all modelled pathways, global surface temperature warming will at least briefly exceed 1·5°C.⁴ Even this temperature increase risks triggering multiple tipping points in the climate system including permafrost melt, which releases methane, a potent greenhouse gas, further setting the stage for worsening wildfires.² Simultaneously, the burning of wildfires intensifies global warming: greenhouse gas emissions from Canada's 2023 wildfires are estimated to constitute more than double Canada's planned cumulative anthropogenic

emissions reductions in 10 years.⁵ Mitigation of anthropogenic greenhouse gas emissions is key. A study found that carbon emissions related to 88 fossil fuel and cement manufacturers contributed 48% of the rise in vapour pressure deficit and 37% of the cumulative area affected by wildfires between 1986 and 2021 in the western USA and Canada.⁶

International consensus with regard to the need for climate-resilient health systems is strong. The 2024 World Health Assembly passed a climate and health resolution and made climate-resilient, low-carbon health systems the number one priority of its work programme for 2025–28.⁷ More than 80 countries have joined the Alliance for Action on Climate Change and Health and 140 have signed the COP28 Declaration on Climate and Health.^{8,9}

Although momentum around commitments is building, the mobilisation of human, political, social, and financial capital required to implement sustainable health care is lagging. Medical curriculum surveys show that the effects of climate change and air pollution are covered in only a few curricula worldwide,¹⁰ and that health professionals are unsure of how to counsel patients or policy makers.¹¹ In 2022, only 11 (17%) of 64 countries committed to building climate-resilient health systems via Alliance for Action on Climate Change and Health had carried out a vulnerability and adaptation assessment.^{1,12} In 2022, only 126 (70%) of 180 countries reported high to very high implementation rates for health emergency planning, management of emergency response, and logistical and supply chain management.¹ Planning and preparation were least complete in low-income countries, many of which are disproportionately affected by climate emergencies.¹ Current disaster plans generally do not account for projected future risks.¹³ The climate competence of other

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*Joint first authors

Department of Information Systems and Business Analytics, College of Business, Florida International University, Miami, FL, USA (A J Hertelendy PhD); Disaster Medicine Fellowship, Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA, USA (A J Hertelendy, G Ciottone MD); Cummings School of Medicine, University of Calgary, Calgary, AB, Canada (C Howard MD); Dahdaleh Institute for Global Health Research, York University, ON, Canada (C Howard); Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY, USA (C Sorensen MD); Department of Emergency Medicine, Columbia University Irving Medical Center, New York, NY, USA (C Sorensen); Menzies Health Institute Queensland, Griffith University, Gold Coast, QLD, Australia (J Ranse PhD); Department of Psychiatry, Faculty of Medicine, Dalhousie University, Halifax, NS, Canada (E Eboreime MD PhD); Environmental Health Services, BC Center for Disease Control, Vancouver, BC, Canada (S Henderson PhD); School of Health Related Research, University of Sheffield, Sheffield, UK (J Tochkin MA); Health Emergency Management, Vernon, BC, Canada (J Tochkin); Harvard Medical School, Harvard University, Boston, MA, USA (G Ciottone)

Correspondence to:
Dr Attila J Hertelendy, Disaster Medicine Fellowship, Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA 02215, USA
ahertele@bidmc.harvard.edu

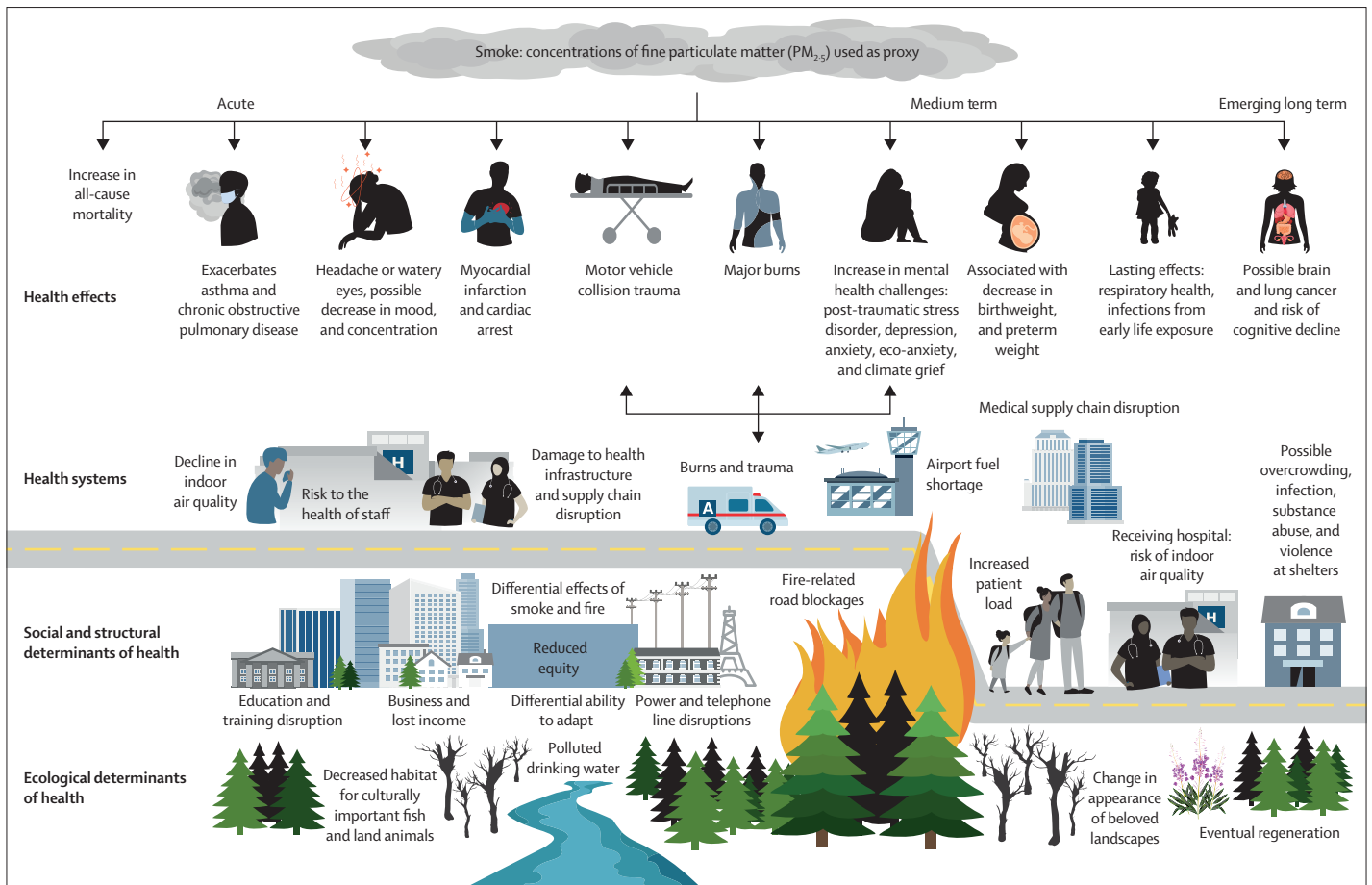


Figure 1: Health and health system effects of smoke and fire

disciplines cannot be assumed: for example, integration of a climate lens into engineering training is incomplete.¹⁴

The absence of government commitment and health system mobilisation does not keep wildfires at bay. Wildfires frequently affect forested areas surrounding small, rural communities with few health staff, many of whom have multiple roles within outpatient, inpatient, health system management, and emergency response capacities. In the midst of overstressed resources, health systems in many regions are still stretched in the wake of COVID-19. This vulnerability leaves front-line health-care providers to manage smoke-related presentations and mental health effects related to climate change for which they have often not received instruction. Meanwhile, at a health systems and emergency management level, the capacity is not always present to do a climate-informed comprehensive assessment using an all-hazards approach, resulting in little awareness of climate risks, and in turn, preparedness. Even in a high-income country such as Canada, the successful evacuation of two 100-bed subarctic hospitals was accomplished primarily thanks to quick thinking, as opposed to assessment, planning, and rehearsal.^{15,16} Comprehensive frameworks for climate-resilient health

systems are designed for public health audiences and long-term visioning¹⁷ and can be unwieldy to implement. Currently, no frameworks exist that are specific to wildfires.

This Review aims to present the beginning of a practical framework to guide health systems leaders facing severe wildfire risks. Developing an empirically derived and theoretically informed framework for health systems adaptation for wildfires is beyond the scope of this paper. Preparing for and responding effectively during a severe wildfire season requires competencies including: awareness of the major health effects and how to manage them; preparation of the health infrastructure and health workforce to manage surges; emergency management and precise, timely communication among many stakeholders and vulnerable communities; and planning for reopening and catch-up with regard to missed patient appointments in the face of what might be reduced systems capacity. Exact demands will differ depending on whether a health system is threatened directly by wildfires or is part of a community at a greater distance from the wildfires. Given low levels of wildfire curriculum content and a rapidly evolving evidence base with

regards to health and health systems effects, we assume busy practitioners with no previous knowledge of wildfires. We first summarise the major health effects of wildfires, from direct trauma, to smoke-related effects, to mental health challenges. We then discuss commonalities of existing climate-resilient health-care and disaster management frameworks and integrate them into an approach that addresses issues of health infrastructure, health workforce, and emergency management before, during, and after wildfires.

Overview of the effects of wildfires on health

Direct trauma

Residents and emergency responders in close proximity to fires are at risk of burns, injuries, motor vehicle accidents, and death.^{18,19} Dense smoke can reduce visibility to such an extent that driving and flying become more hazardous, increasing the risk of trauma. The prevalence of trauma and burns resulting from direct exposure to wildfires varies from none or very small numbers despite a large fire, to many people affected.²⁰ The Black Saturday bushfires in Australia were the deadliest ever bushfire event, resulting in 173 casualties and 414 people injured.²¹ The fire in Maui in 2023 killed close to 100 people and caused more than \$5.5 billion in damage.^{22,23} Nine patients with burns were flown out of Maui to Honolulu, the largest number of admissions from a single incident in the burn unit's history.²³ People with major burns can pose a great challenge for smaller, rural health-care facilities, since these individuals frequently require intubation and intensive care, quickly overwhelming capacity in terms of ventilation as well as in the medical evacuation resources needed for transport to a burn centre (figure 1).

Wildfire smoke exposure

When considering the population health effects of wildfire smoke, it is key to acknowledge how smoke differs from other sources of ambient air pollution, such as traffic and industry.^{24,25} First, smoke is a more complex and dynamic mixture of pollutants, for which we often use particulate matter (PM) of less than 2.5 microns in aerodynamic diameter (PM_{2.5}) as a convenient proxy. Second, the toxicology of wildfire smoke PM_{2.5} might be different from the toxicology of PM_{2.5} generated by other sources. Third, the magnitude of PM_{2.5} exposure is much higher in case of wildfires than it would be for mobile or point sources that have a steady emission rate. Fourth, the exposure is highly variable in both space and time depending on the fuels, the fires, and the weather.²⁶

Wildfire smoke is a uniquely complex and dynamic form of air pollution made up of both gases and particles. The primary gases emitted by wildfires include carbon monoxide, ammonia, oxides of nitrogen, volatile organic compounds, and polyaromatic hydrocarbons.²⁷ These gases then inter-react with each other and the atmosphere

to form secondary gases, particularly ground-level ozone.²⁸ Wildfires emit vast quantities of particulate matter that ranges from less than 0.1 to more than 10 micrometres in diameter that tend to aggregate together as they get further from the fire source.²⁷ The composition of this PM is also complex, with varying concentrations of organic carbon, elemental carbon, heavy metals, and other constituents.²⁷ Although the evidence is still scarce, some fuel types, especially anthropogenic materials, seem to produce more toxic smoke than others.^{29,30}

Despite all this complexity, the mass concentration of PM_{2.5} is known to have profound effects on human health and is thus widely measured.³¹ Ambient PM_{2.5} concentrations during periods affected by wildfire smoke can change quickly, with high variability within and between days.³² In many high-income countries background 24-h average PM_{2.5} concentrations are typically less than 25 µg/m³. A moderately smoky day might have concentrations up to 100 µg/m³, where a very smoky day can exceed 250 µg/m³. During the smokiest hours concentrations might exceed 1000 µg/m³.³³

Evidence on the health effects of wildfire smoke exposure is now growing rapidly, but the number of studies is still small when compared with the literature on ambient air pollution from other sources. Clear evidence exists that short-term exposure to wildfire smoke has immediate effects on respiratory health, especially for endpoints related to asthma.¹⁹ Some studies suggest that the acute respiratory effects of PM_{2.5} from wildfire smoke are greater than those from PM_{2.5} in the typical background air mixture.^{34,35} This difference might be due to unmeasured co-pollutants or different composition of the smoke particles. Evidence of the association between short-term wildfire smoke exposure and increased risk of severe cardiovascular events, such as out-of-hospital cardiac arrest and myocardial infarction, is growing.³⁶ Finally, there is emerging evidence on a much broader range of wildfire smoke exposure outcomes, including diabetic control,³⁷ kidney disease,³⁸ and cognition.³⁹

There is much more limited evidence on the longer-term effects of wildfire smoke exposures, especially in populations that are repeatedly exposed. A 2022 Canadian study found higher incidence of lung and other cancers in areas with closer proximity to wildfire over a 20-year period.⁴⁰ Another study on a small cohort exposed to coalmine fire smoke in 2014 had similar findings.⁴¹ Other studies have found long-term decrements to lung function following a severe wildfire season⁴² and higher rates of influenza infection.⁴³ Evidence is also emerging that exposure to wildfire-related PM_{2.5} increases risk of incident dementia.⁴⁴ Much more work is needed on the longer-lasting effects of wildfire smoke exposures.

Three groups of particular concern with respect to long-lasting effects of wildfire smoke are the developing fetus,⁴⁵ infants, and young children, whose exposure could lead

to health effects that persist through the life course. Again, current evidence is scarce. Wildfire smoke exposure during pregnancy has been associated with reduced birthweight,^{46–48} increased birthweight among mothers with gestational diabetes,⁴⁹ preterm birth,^{46,50} stillbirth,⁵¹ and increased otitis media and lower respiratory infections in the first year of life.⁵² Research on infant monkeys has found reduced lung size and immune function⁵³ among exposed groups, with potential evidence of epigenetic effects.⁵⁴ Further research from the Australian coalmine fire cohort has found increased respiratory risk in children.⁵⁵ Following up such cohorts through young adulthood will improve our understanding of the long-term effects of wildfire smoke exposure.

Mental health

Wildfires have short-term and long-term psychological effects on affected people, first responders, and the public. Within 3–6 months of wildfires, 24–60% of adult survivors might experience symptoms of post-traumatic stress disorder, 25–33% might experience major depressive disorder, and 25–33% might have anxiety disorders.^{56–58} Resilience, being the capacity to handle adverse experiences, diminishes after wildfire exposure.⁵⁹

Eco-anxiety, characterised by overwhelming feelings of helplessness, hopelessness, fear, and despair in the face of climate change and environmental threats, is becoming prevalent among younger generations worried about their future on a warming planet.⁶⁰ Exposure to traumatic wildfires can exacerbate eco-anxiety and climate grief in children and youth.⁶¹ Although psychological distress tends to wane over time, symptoms can persist for years after disaster.^{62,63} Despite this burden, mental health is often not prioritised in disaster preparedness and response. The seasonal nature of wildfires can result in recurrent exposures and increased mental health burdens. Fire-related risk and heavy smoke can result in a reduction of important cultural land-based activities including fishing and berry gathering.⁶⁴ The changed landscapes resulting from severe wildfire seasons can affect Indigenous land-based practices and mental health more broadly.^{64,65}

Existing frameworks for health system preparedness and response

Climate-resilient health systems

The WHO Operational Framework for climate-resilient and low-carbon health systems is designed to assist decision makers in health systems, including public health agencies, with comprehensive planning.¹⁷ Overarching goals include managing climate-related health risks, developing health system capacity, and ensuring a long-term vision and adaptive management. The framework uses six building blocks for health systems: financing; leadership and governance; health workforce; health

information systems; climate resilient and low-carbon infrastructures, technologies, and supply chain; and service delivery, including climate-informed health programmes, and emergency preparedness and management.¹⁷ Evaluation of health risks includes assessment of vulnerabilities, including: demographic, geographical, gender, and others; climate-related hazards including heat, sea-level rise, air pollution, vector distribution and ecology, and water scarcity and food; and exposures, including to the community, health workforce, infrastructure, and energy, water, food, and health systems.⁶⁶ The framework describes how health systems head into a given stressor with various levels of capacity, and that various resulting pathways are then possible. These include collapse, transformation, and recovery to levels of function that are worse, similar, or better than pre-event.¹⁷

Similarly, the Canadian Climate Change and Health Vulnerability and Adaptation Assessment provides a six-step process.⁶⁷ The assessment invites practitioners to identify priority health hazards, describe current risks including vulnerabilities and capacities, project future health risks, identify and prioritise policies to improve climate resilience, establish an iterative process for managing and monitoring risks, and examine the potential health co-benefits and co-harms of adaptation and greenhouse gas mitigation.⁶⁷ The assessment utilises the WHO health system building block framework and is very comprehensive.⁶⁷

The US Primary Protection: Enhancing Healthcare Resiliency for a Changing Climate⁶⁸ is a comprehensive guide aimed at bolstering the resilience of health-care facilities against the effects of climate change. Developed by the US Department of Health and Human Services, this guide addresses a range of vulnerabilities related to health-care infrastructure. The guide is focused on health infrastructure, employs a multi-hazard assessment, addresses land use planning and protection of clinical care facilities and the environment. The guide emphasises the need for health-care facilities to adapt to increasing extreme weather events by adopting a five-element planning framework. This framework includes assessing climate risks, planning infrastructure resilience, ensuring essential clinical services, and integrating environmental protections.

Finally, in 2023, UNICEF published a very thorough report, which summarises the latest evidence on the health harms of smoke in children and contains recommendations for how to mitigate the risk of exposure to environmental pollutants such as wildfire smoke.⁶⁹

Also, of use for practitioners preparing for wildfire season are disaster management and emergency management frameworks. The Sendai Framework for Disaster Risk Reduction places major emphasis on addressing climate-related risks and integrating climate change adaptation into disaster risk reduction strategies. The framework outlines four main priorities for action: understanding disaster risk, strengthening disaster

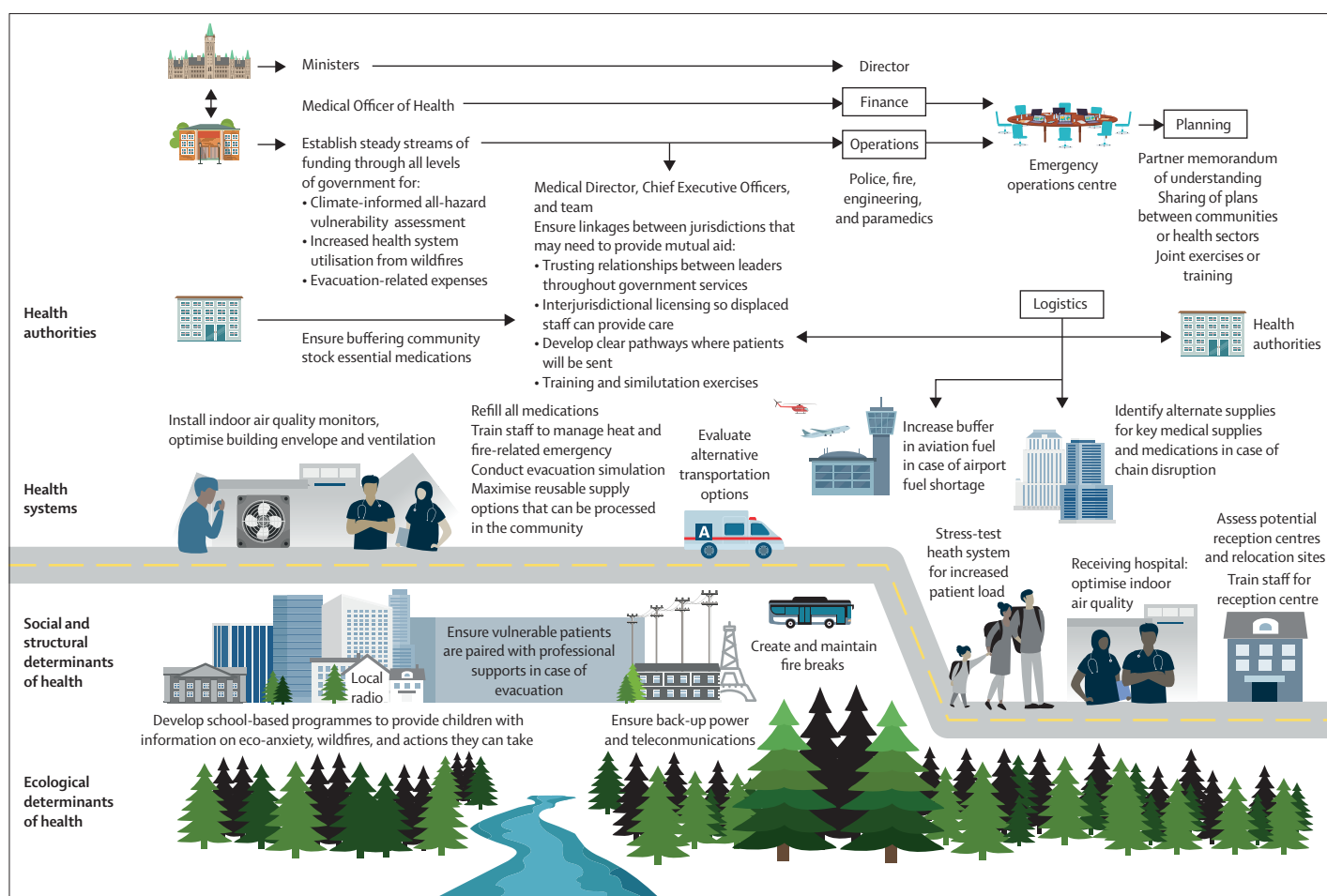


Figure 2: Improving health system performance before wildfire season

risk governance, investing in disaster risk reduction for resilience, and enhancing disaster preparedness for effective response and recovery. In the health-care context, the framework includes strengthening health infrastructure, improving emergency preparedness, and fostering collaboration across sectors to enhance overall resilience to climate-related disasters.⁷⁰

An empirically derived and theoretically informed framework developed in Canada emphasises the necessity of surfacing and prioritising ethics and values, including equity, trust, public protection, reciprocity, duty to care, stewardship, and solidarity. This framework envisions emergency preparedness and response as a complex adaptive system, which includes elements of interconnectivity, emergence, feedback loops, non-linearity, dynamic context, self-organisation, and adaptability.⁷¹ The British Columbia Emergency System framework envisions a process shown in figures 2–4.⁷² The Northern Inter-Tribal Emergency Preparedness Guide for Community Members includes detailed guidance for community members returning to homes that might have been affected by wildfires.⁷³

Proposed approach

Given that in many parts of the world wildfires occur at a distinct time of year, which imparts a temporal element to preparation and planning that is aligned with disaster medicine and emergency management frameworks, an approach is suggested that integrates these aspects with elements of climate-resilient health systems frameworks. This approach is combined with the WHO's six building blocks of health systems, and elements applicable to wildfires from the climate-resilient health system frameworks listed. Although a comprehensive climate-smart planning exercise and all-hazards approach to emergency management is still recommended, this lens provides a framework for practitioners staring down a predicted severe wildfire season to verify that major elements of planning and response have been considered. The time periods identified are mitigation (throughout), before (preparedness), during (response), and recovery (after; tables 1–4). Each category is discussed with reference to wildfire season in its entirety, given that multiple fires in a single season often result in stuttering effects and sometimes more than one evacuation of any given health system.

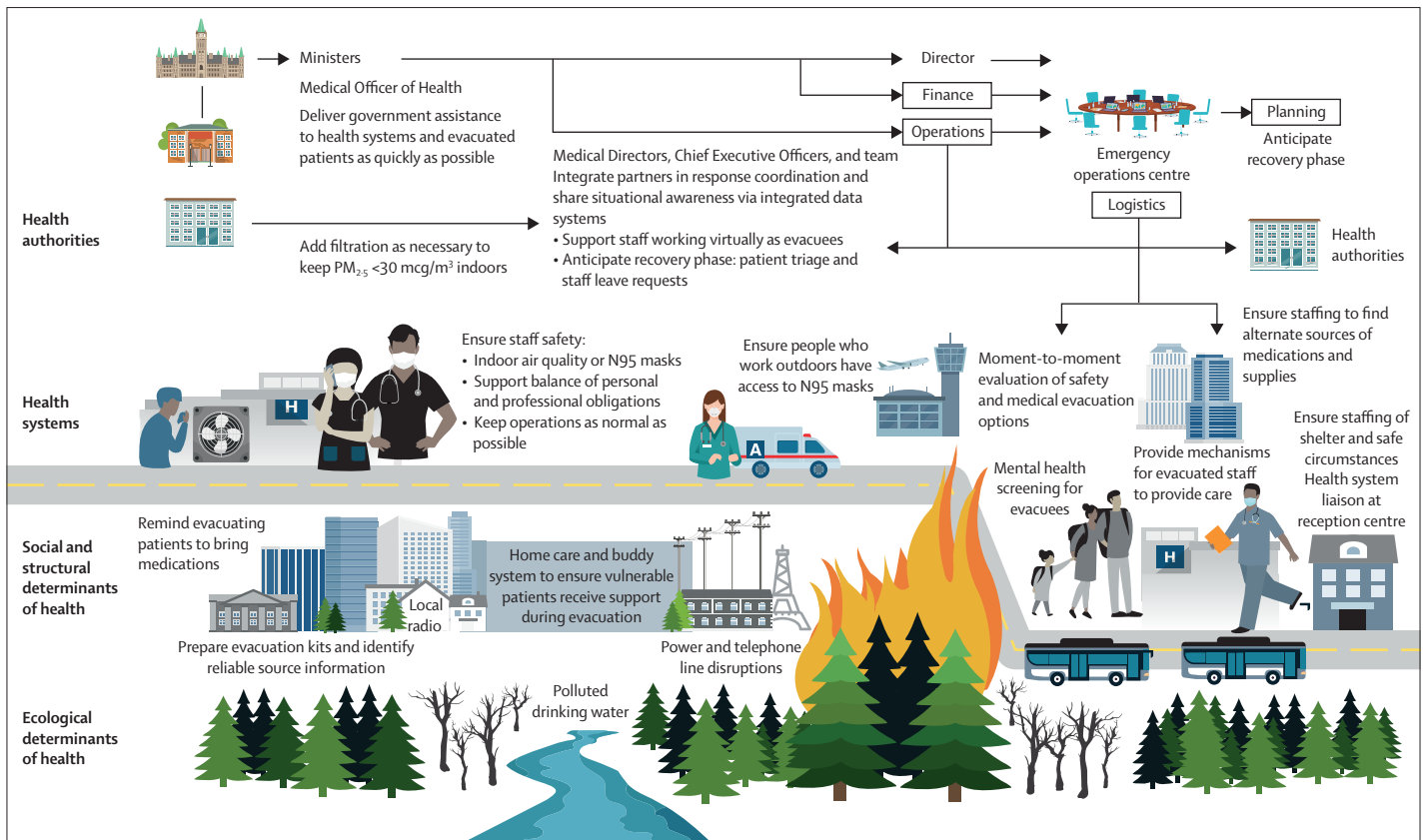


Figure 3: Improving health system performance during wildfire season

Before the wildfire: health systems preparation

Financing of preparedness for wildfires might be challenging at a time when many health systems' leaders do not know what they do not know.¹⁰ Recent WHO and country-level commitments made at the 2023 World Health Assembly should be brought to their attention. (figure 2).^{8,74}

Leadership in communities likely to provide mutual aid during wildfire season must establish trusting relationships before wildfire season (table 1). Hospital evacuation scenarios should be considered on an inter-agency basis well before wildfire season, enabling decisions to be taken and actioned transparently and efficiently during the wildfire. The health workforce should receive training on the management of wildfire emergencies, including physical trauma, smoke exposure, and extreme heat injuries. Health-care workers should be able to interpret air quality information and describe the appropriate response for patients with different vulnerabilities (table 2). Health-care staff should be prepared for rapid evacuation and be ready to ensure continuity of operations in the case of loss of power.⁷⁵ Identified vulnerabilities should be stress-tested through realistic, regular drills done by experienced, credentialed emergency and disaster experts.^{76,77} Health information systems should be created to inform the community (table 1).

Infrastructure must be upgraded to ensure resilience to fire and smoke (table 3). Wildfire smoke can affect communities and hospitals thousands of miles downwind,⁷⁸ increasing demand for emergency services.⁷⁹ At the same time, wildfire smoke can affect the indoor air quality in patients' homes and health-care settings.⁸⁰ Indoor infiltration of outdoor wildfire smoke depends on building-specific properties, such as the design of the heating, ventilation, and air conditioning (HVAC) system, windows, doors, number of storeys, and building materials. It is imperative to assess whether building repairs are required and what types of filters can be used with HVAC systems. Indoor air quality sensors should be installed to assess in real time whether supplementary indoor air cleaning might be required to keep PM_{2.5} in the low-risk zone of less than 30 mcg/m³.⁸¹ When these actions are not achievable it might be impossible to use parts of the building safely, such as operating rooms.⁶⁸

Maintaining health services can be challenging (table 4). Residents in areas affected by wildfires should be educated to keep track of reliable information and community evacuation plans.⁵ Patients should be advised to carry a list of their medications and be provided with refills on prescriptions. Data on the effectiveness of prophylactic medication use for patients with respiratory disease are insufficient.⁸² Setting up

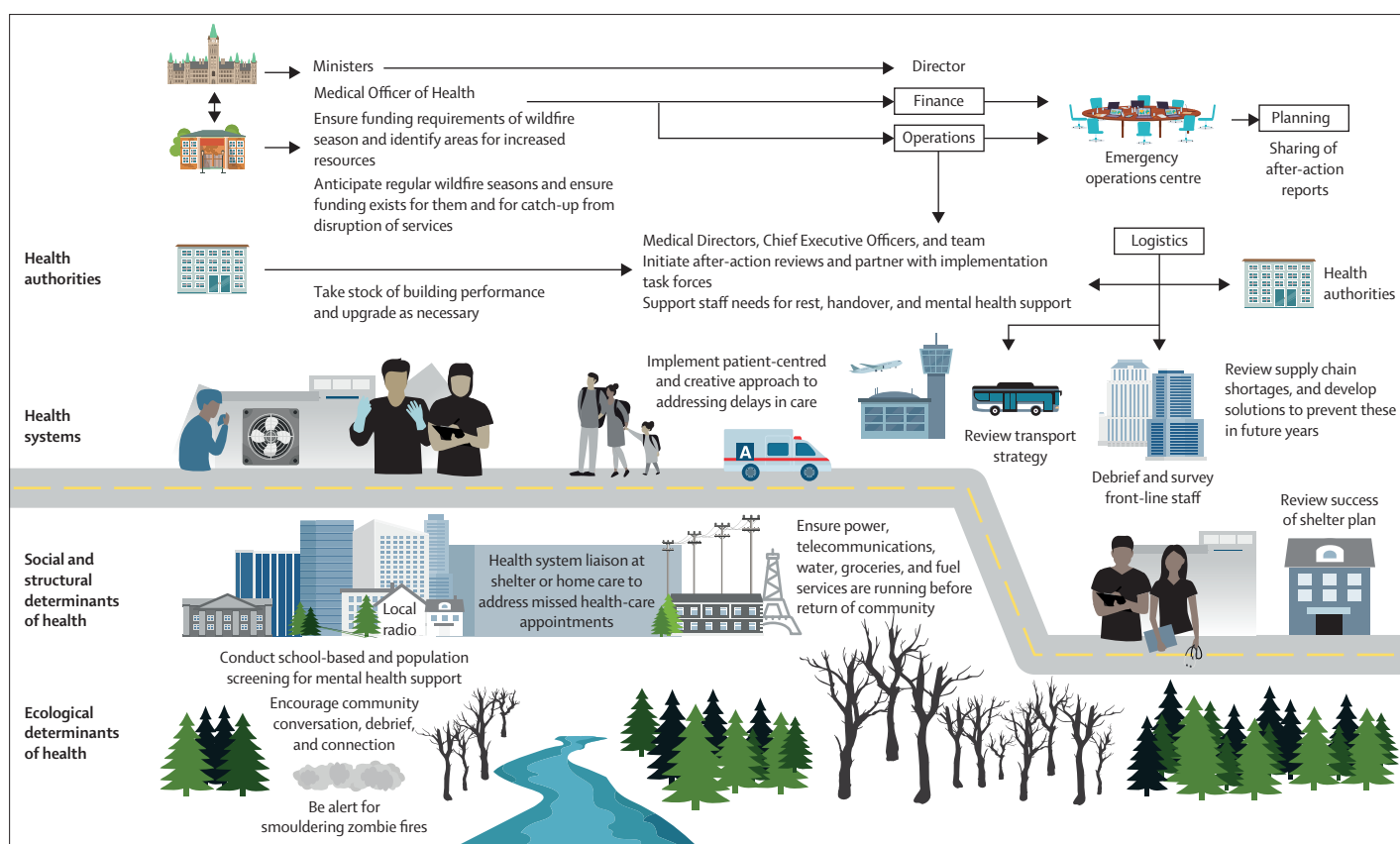


Figure 4: Improving health system performance after wildfire season

interjurisdictional professional licensing and systems for virtual care and in-person facilities, so that displaced health-care workers can bolster health services within host communities, can reduce how overwhelmed receiving health systems are.

Particular attention should be paid to wildfire preparedness in hospitals and health systems located at wildland–urban interfaces.^{83,84} When local health-care facilities lose functionality, patients must be transferred to other nearby care facilities, creating a surge that might exceed capacity.⁸⁴ In addition, there might be multiple health-care facilities sending patients that converge on a single site. This situation can completely overwhelm health systems. This has been highlighted as a risk within California, USA, health-care centres.⁸⁵ British Columbia, Canada, has experienced similar challenges, with health system capacity additionally strained by staffing shortages due to evacuation alerts that also affect health-care staff. A provincial staff-sharing model between health authorities has been developed to alleviate staffing capacity issues. Alternate (under-used or unused) long-term care sites are also being identified and retrofitted to accept potentially evacuated residents. For example, the 2017 severe wildfires in the interior of British Columbia, Canada, affected 19 health facilities, led to the evacuation of 880 patients, and caused the

displacement of 700 health-care professionals.⁸⁶ This event was followed in 2023, with the evacuation of the 100-bed territorial hospital in Yellowknife, a complex operation involving a military airlift and coordination with multiple hospitals in the provinces of British Columbia and Alberta.¹⁵

Preparedness planning should incorporate mental health strategies focused on building individual and community resilience and coping skills, and provide information on where and how to access resources and supports.⁸⁷ These programmes should be adapted to meet the needs of vulnerable groups, such as children, older people, and rescue workers.^{59,88} School-based programmes can provide children with age-appropriate climate change information, eco-anxiety coping strategies, and peer support.⁸⁹ Training community health workers in psychological preparedness, screening, and psychological first aid can enhance community resilience.⁹⁰

Considering that remote and rural communities are frequently most affected, and these communities often do not have access to mental health services, digital mental health programmes designed for the general population, health-care providers, and first responders can help close the access gap, even in resource-constrained settings.^{91,92} The cultural determinants of health should be taken into

	Mitigation (throughout)	Before (preparedness)	During (response)	Recovery (after)
Financing	Encourage community members to have up-to-date house insurance that covers wildfires; establish mechanisms for a steady stream of funding through all levels of government for both health systems function and to aid patients having to cover evacuation expenses; and obtain funding for at-home air purifiers for vulnerable people.	Develop a system, possibly text-based, via which community members could collect funds from government-sponsored grant programmes to defray evacuation-related expenses.	Deliver governmental financial assistance to evacuated patients as quickly as possible. This help might include private sector and non-governmental organisation support.	Review funding requirements of the wildfire season and identify priority areas for increased resourcing. Anticipate regular severe wildfire seasons and ensure funding exists for fall catch-up from disruption of health services during the summer.
Leadership and governance	Ensure trusting relationships exist between health systems' leaders in jurisdictions that might need to provide assistance during evacuations, as well as with Indigenous organisations, emergency services, and decision makers at various levels (municipal, regional, and national) to ensure the sharing of information and consultation with regard to key elements of planning and implementation. Ensure the local knowledge of Indigenous people is involved in designing the community and health system response to wildfires. Commit to ensuring that everyone in a leadership role is trained to lead emergency operations and that all members of the health system understand their roles.	Take responsibility for initiating, funding, and completing climate-related vulnerability assessments. Recognise and normalise the fact that climate-related and disaster-related emotions, such as fear, anxiety, guilt, and anger might affect the decisions and behaviour of leadership, teams at all levels, and patients, and model practices designed to help develop insight into these, and to optimise both individual and team wellbeing and performance; and plan for redundancy within health leadership to ensure a mid-level planning team with high-level authorisation who can plan for recovery while on-the-ground leadership manages the evacuation.	Integrate partners in response coordination: share situational awareness through integrated data systems, adapt command and control model to be less command focused and more inclusive and culturally sensitive to affected communities, and designate a mid-level planning team with high-level authorisation to organise the recovery while on-the-ground leadership manages the evacuation.	Initiate a post-event evaluation to determine strengths and weaknesses of the management of wildfire season and to identify ways to improve future responses. Partner after action reviews with an integrated task force to implement improvements; recognise that handover might need to occur between the team that planned and executed an evacuation and a new team to lead the recovery.

Table 1: Financing, leadership, and governance

account, recognising that Indigenous ways of coping after wildfires, for example, might be different to those of settlers who might have a different relationship to the Land or Country, and to one another. Culturally appropriate interventions, such as sharing circles might be helpful in Indigenous communities.⁹³ Emergency management services coordinate different levels of government, and integrate the efforts of social institutions, the private sector, communities, and first responders (table 2). Health systems are included within broader emergency management structures that interface with other actors for greater coordination and to expedite information sharing.⁹⁴

Planning should include risk–benefit analyses related to potential challenges to land-based evacuation due to long driving distances and infrequent fuelling stations, as well as highway safety and potential for road closures due to fires. Air quality issues in ambulances should be anticipated and portable air filters added as needed. Air-based evacuation planning should consider the potential for decreased visibility due to smoke to interrupt flights and for the airport to run out of fuel.

Emergency management in North America has a long history of focusing on evacuation to protect populations. However, evacuations are associated with substantial health harms compared with sheltering in place,⁹⁵ which has been seen as more appropriate in countries such as the UK.⁹⁶ The benefits of sheltering in place include reduced emotional trauma,⁹⁷ mortality, and reoccurring hospitalisations.⁹⁸ Moving forward, decision making should be informed by community co-development of wildfire plans, emerging evidence regarding long-term effects of smoke, and the changing characteristics of wildfires as temperature and precipitation patterns shift.

During the wildfire

Leadership must prioritise safety and health of staff and patients (table 1, figure 3). Infrastructure in fire-prone areas should be monitored to optimise air quality. Isolating emergency department ventilation systems and enabling recirculated air during emergency conditions should be considered. When PM_{2.5} cannot be maintained at less than 30 mcg/m³, portable scrubbers can be added (table 4).⁶⁸

The health-care workers also face risks: staff might be unable to get to work due to road closures, and hospitals must then enact contingency staffing plans (table 1). Health services should be run with as much normalcy as possible, with staff actively advising all patients to have evacuation plans in place. Health services should work closely with social workers and case managers to ensure that vulnerable patients have access to transportation and housing in the case of evacuation (table 3). Having home care patient staff establish links with health services in the host community during evacuations can greatly assist the evacuated public who might require support in their temporary residences. Basic health services might need to continue to operate in evacuated communities to provide care for fire fighters or local law enforcement who are tasked with the management of those unwilling to evacuate.¹⁵ This task also might require paramedic staff to be placed at egress points within the evacuated community.

Emergency management operations centres liaise with health-care services, which ensures open communication and highlights health risks to areas with encroaching evacuation alerts or orders. Plans must be shared across agencies, such as evacuation criteria versus sheltering in place. During the 2017 British Columbia wildfires, health centres and long-term care sites evacuated before

	Mitigation (throughout)	Before (preparedness)	During (response)	Recovery (after)
Health workforce	Ensure optimisation of health-care staff health and wellbeing through good access to well fitted respirators, health care, and medication. Create a plan for the occupational health and safety for wildland firefighters, as they are exposed to major health and safety risks. Develop and maintain regional licensure for health-care professionals to ensure displaced staff are still able to serve patients when they themselves are also evacuated. These arrangements might include bilateral agreements with other jurisdictions to recognise licensure in the case of cross-jurisdictional evacuation. Ensure there is a staffing plan for possible relocation sites; develop clear expectations on what evacuated staff will be asked to do professionally when they themselves are affected, and ensure support for them (housing with electricity and internet to support virtual care, pay, etc).	Train health-care staff in management of heat-related and smoke-related emergencies and community health workers in psychological preparedness, including the ability to screen for mental health problems and deliver psychological first aid. Ensure staff are prepared for rapid evacuation and have arrangements with their families with regard to childcare and evacuation in case they are on duty when community evacuation occurs. Plan which staff might be willing to stay behind to provide care to emergency workers in case of an evacuation. Ensure staff in communities that could possibly be involved in mutual aid during evacuations are familiar with the cultural determinants of health of their respective populations.	Protect the health of staff and patients by monitoring and optimising indoor air quality in health-care facilities and providing N95 masks when $PM_{2.5} > 30$ mcg/m ³ . Place portable air scrubbers in units as needed to improve air quality; support staff as they attempt to manage childcare, pet care, and the safety of themselves and their families in the midst of sometimes uncertain and rapidly shifting circumstances, in which they are also called upon to contribute in their professional capacity. Recognise that some evacuated staff will not be able to contribute in a professional capacity in the host community due to uncertainty in living arrangements, no childcare, the exacerbation of physical or mental health challenges, or other factors.	Consider health workers' mental and physical health needs and provide appropriate care and support; consider developing recovery groups to conduct after-action reviews and lived experience learning exercises; and anticipate the need for higher than usual numbers of staff to go on leave post-evacuation.
Health information systems: guidance for community	Identify sources of reliable news, weather, and smoke information and encourage the community to follow public health advice appropriate for the situation, with pregnant women, infants, children, outdoor workers, older people, and individuals with pre-existing conditions considered more vulnerable; consider providing at-home air filtration devices to patients with pre-existing vulnerabilities; in case family members are experiencing shortness of breath, chest pain or chest tightness, cough, extreme sadness, worry, or nightmares then seek medical care; and if you are in an area with potential coexisting heat and wildfire emergencies, consider purchasing an air conditioning unit to cool the air if windows are closed due to wildfire smoke.	Refill medications for patients with pre-existing smoke-sensitive medical conditions. Prepare an emergency evacuation kit including medications, chargers, comfort toys or objects, important documents, and N95 or KN95 masks. Prepare an emergency evacuation plan and ensure the whole family is briefed (including children) and that jerry cans or water jugs are procured as necessary. Create fire-resistant zone around house. Collaborate with social workers and case managers as well as creating a buddy system in your community to ensure older and vulnerable people have someone who can check in on them during heat and wildfire episodes. Encourage active building of community-based relationships via social activities in order to enhance mutual aid during wildfire seasons.	Evacuate immediately when the house is at risk of fire, and follow community evacuation orders. Ensure all outdoor workers have access to well fitted N95 or KN95 masks for smoky times and follow public health advice with regard to smoke. Stay inside with windows closed and an air filtration device running as needed. Aim for an indoor air quality of $PM_{2.5}$ of < 30 mcg/m ³ ; avoid cooking with gas or biomass stoves. ⁶⁹ Optimise overall wellbeing during smoky wildfire seasons by aiming for an 8 h sleep opportunity, exercising in cleaner air or with a mask, minimising caffeine and alcohol consumption, spending quality time screen-free with family, and going outside to enjoy nature and community during clean air windows.	Submit insurance claims as need be for evacuation costs, damage to infrastructure, and health care; undertake home upgrades or add air filtration as necessary to improve indoor air quality and fire safety for the next wildfire season; observe family members, particularly children, for changes in behaviour, such as trouble sleeping, withdrawal, or regression in milestones that could indicate mental health trouble from wildfire-related experiences. If undertaking clean up, first ensure the area is safe, ventilate the home, and remove soot from surfaces with a vacuum or a cloth with hot, soapy water. ⁷¹

Table 2: Health workforce and health information systems

evacuation orders being put in place. These uncoordinated actions caused challenges for communities where residents decided to stay during an alert, as health services within the community were moved out. This situation can also be taxing for ambulance providers as it creates the potential for longer transportation times and heightened service requirements (table 1). Health equity and access to health services is a key theme during disasters and is a challenge during evacuations caused by severe wildfires.⁹⁹ Cultural sensitivities and the concurrent management of other public health challenges related to infectious disease, substance use, and interpersonal violence need to be taken into consideration when assessing and setting up potential reception centres.

Providing shelter for people evacuated can be challenging. Community evacuations during wildfires often take place during heightened tourist seasons.¹⁰⁰ The increased population puts pressure on available commercial accommodations, which typically are at capacity. Given the 2023 case of the Maui, USA, interface fires, there is much value in having tourism officials and

representatives consider how influxes of populations might affect health services. This issue can be alleviated with memoranda of understanding with commercial entities and health sector-informed accommodation planning. Considerations must be given to the housing needs of local populations in case houses are lost during a disaster. In British Columbia, travel restrictions have been put into effect to limit tourism to allow for commercial lodging to have the necessary capacity to house displaced local populations.

After the wildfire: recovery

Financing is key: having a steady stream of recovery funding through all levels of government is necessary to maintain health and social services beyond immediate evacuation financial assistance (table 1, figure 4). Leadership should ensure a phased re-entry plan in which experts first deem a community safe from fire. Next, essential staff for key services including water, sewage, groceries, and health care are allowed to return. Finally, residents are permitted home (table 1).¹⁰¹

	Mitigation (throughout)	Before (preparedness)	During (response)	Recovery (after)
Infrastructure	Coordinate with municipalities to ensure preparation includes the creation and maintenance of fire breaks as necessary and the removal of brush from around community buildings and health-care facilities; identify cleaner air shelters, which should include all public buildings, including recreation facilities, community gathering spaces, health-care facilities, libraries, and schools; ensure the locations of cleaner air shelters are well communicated to the community. Establish a threshold of outdoor air quality, at which public buildings, such as recreation facilities will be open to the community without charge.	Ensure all new buildings can cope with high smoke burdens while maintaining low-risk levels of indoor air pollution; repair windows and leaky elements of building envelope, upgrade heating ventilation air conditioning systems, and create a staging area at the entrance to buildings. Ensure that these clean air shelters are equipped with sensors to track particulate matter less than PM _{2.5} both inside and outside.	Aim for a PM _{2.5} of <30 mcg/m ³ in clean air shelters, understanding that no level of PM _{2.5} is without risk, and that WHO 24-h target concentration is less than 15 mcg/m ³ . ⁷² Low risk: 0–30 mcg/m ³ ; moderate risk: 31–60; high risk: 61–100; very high risk: >100; monitor indoor air quality to track success in achieving the above low risk standard, and add supplemental air cleaning as required to reach PM _{2.5} of less than 30 mcg/m ³ .	Take stock of performance of building stock and make repairs to building envelope and upgrade air filtration systems as necessary; and fire smart buildings found to be overly vulnerable over the course of the wildfire season.
Supply chain	Ensure in-community buffer stocks of frequently prescribed medications, such as inhalers for asthma and chronic obstructive pulmonary disease. These medications must be ready to compensate for both increased prescription and possible delay in delivery as a result of highway blockage and disruption of flights due to smoke or fuel shortages.	Identify new potential sources for key equipment and alternative transportation routes and strategies in case of a disruption of business-as-usual; minimise single-use medical supplies in favour of reusable options that can be processed in the community.	Ensure staffing and flexible funding to find alternate sources of medications and supplies as needed.	Review supply chain shortages and develop alternate plans for next wildfire season.
Technologies	Develop and maintain regionally integrated health and social care records to enable displaced patients to be easily tracked and served by possibly displaced staff.	Ensure back-up power supply for all essential technology.	Ensure adequate staff capacity and emergency funds are available to help solve technological challenges.	Review technological challenges, share lessons learned with other jurisdictions, and develop alternate plans for next wildfire season.

Table 3: Climate-resilient Infrastructure, technologies, and supply chain

Health-care workers are under pressure during a severe wildfire season, so the workers’ mental health needs to be considered, especially the individuals who have been affected due to evacuation or losses of personal property.¹⁰² Recovery groups can do after-action reviews and lived experience learning exercises, which might include considerations for future environmental design, hazard proofing communications, and enhancing early warning system infrastructure, as well as disaster risk reduction improvements (table).⁸³ Health services should resume normal function as soon as possible. Community recovery teams that include health actors can assess recovery needs, coordinate partners in reopening health facilities, and incorporate lessons-learned after the event (table 4).

Resilience to hazards such as wildfires is enhanced by boosting hospital capacity and through robust linkages within the community.¹⁰³ Health-care systems that are able to maintain normal operations while responding to events and transition to recovery following an event allow for improved societal resilience.¹⁰⁴ Conversely, health-care resiliency is linked to the level of adaptation of the community in which the system resides. It is imperative that health-care organisations work with community partners and take an active role in building local resiliency across the disaster cycle.¹⁰⁵ The local knowledge of Indigenous people should be included in decisions designed to increase resilience. In Maui, for instance, a return to traditional agroecology could enhance food security, while also reducing the flammability of the grass-heavy landscape.²²

Mental health sequelae from wildfires are common but often subtle in contrast to physical trauma, with

implications for case identification and triage. Population screening and surveillance can provide prevalence estimates of mental health conditions to inform pragmatic resource allocation, planning, and delivery of interventions. It is key to triage available psychological support for people most greatly affected or the most vulnerable, such as infirm people or individuals with disabilities. Psychological support can include community outreach services, delivery of psychological first aid, and crisis counselling.¹⁰⁶

Wildfire mental health effects can persist long term if not addressed. Rehabilitation should continue for years, providing psychosocial support alongside physical rebuilding. Ongoing assessment helps identify communities and individuals still struggling to recover economically and emotionally. Schools should integrate climate education, eco-anxiety coping skills, and emotional support services to build student resilience.¹⁰⁷ Community programmes can help people with insurance claims, housing, and the results of disruptions to livelihoods. Workplaces and health-care systems must implement comprehensive, long-term mental health services.

Breaking down silos and funding a healthier future

An all-of-society response is required to optimise wellbeing in the face of severe wildfires. National and subnational frameworks that prioritise wellbeing within budgeting processes provide an opportunity for an integrated approach to funding and implementing adaptation across ministries, as well as a two-way dialogue with ministries of finance and new priorities

	Mitigation (throughout)	Before (preparedness)	During (response)	Recovery (after)
Community	Consider cultural sensitivities and the concurrent management of public health challenges related to infectious disease, substance use, and interpersonal violence.	Develop school-based programmes to provide children with information on climate change, eco-anxiety, actions to take, and peer support.	Ensure good communication between official and informal parts of the disaster response, including linking professional emergency management with community service organizations, and public health communications with local radio.	Conduct population screening and surveillance to estimate prevalence of mental health conditions to inform resource allocation, planning, and delivery of interventions; provide community outreach services and deliver psychological first aid, crisis counselling, and formal treatment; develop comprehensive, long-term mental health services in schools, workplaces, and health-care facilities.
Primary care and outpatient services	Develop and maintain digital mental health programmes for text-based interventions. Ensure vulnerable patients are paired with family or community members who could care for them should emergency services and home care become overwhelmed, or an evacuation take place. Develop a triage framework and a plan for implementation before wildfire season to enable prioritisation of missed appointments during the recovery phase.	Refill prescriptions for all patients to ensure 4–6 weeks of medication are available heading into a wildfire season in which the potential for evacuation is high. Account for likely increased medication use by people with asthma and chronic obstructive pulmonary disease whose symptoms tend to be exacerbated by smoke and remind patients to put medications in their evacuation kits; and review best practices for smoky seasons with patients in terms of where to access air pollution and evacuation-related information, and measures to protect their family from smoke.	Remain flexible to changes in methods of working that might involve shifts to virtual care or care administered in other facilities or jurisdictions. Attempt to maintain regular follow-up appointments as possible during times of disruption to minimise delays in care and a backlog in cases and visits post-wildfire-related disruption; go through list of patients who were receiving active treatment (eg, outpatient intravenous therapy) before the evacuation, and those with upcoming appointments, to identify who: can wait; can wait but need to be prioritised upon reopening; or need care arranged at evacuation location. This analysis requires a schedule that identifies the practitioner responsible for actioning each pathway, with follow-up and contingencies.	Screen patients for mental health challenges after wildfire season; maximise a patient-centred and creative approach to managing patients who experienced delays in care related to wildfire season.
Emergency department	Ensure emergency department team participates in the development of an emergency plan and rehearses it via simulation; prepare to provide scaled-back services even in the case of an evacuation to care for emergency service workers and firefighters.	Stress-test health system capacity for increased numbers of potential patients including people with major burns, motor vehicle collision-related trauma, exacerbations of asthma and chronic obstructive pulmonary disease, myocardial infarction, and mental health challenges. Assess medication supplies and equipment for transport of patients including time to evacuate and time to transport.	Consider increasing staffing levels if outdoor air pollution levels have been high for several days; consider isolating hospital ventilation systems and enabling recycled air. Ensure staff and patients are provided with well fitted N95 masks when $PM_{2.5} > 30$ mcg/m ³ .	Screen patients for mental health challenges after wildfire season; and maximise a patient-centred and creative approach to managing patients who experienced delays in care related to wildfire season.
Hospital-based	Develop clear pathways for where patients will be sent in case of evacuation and which transportation modalities will be used; best when can be accomplished without military assistance, to reduce complexity. Ensure hospital team participates in the development of an emergency plan and rehearses it via simulation.	Stress-test health system capacity for increased numbers of potential patients including people with major burns, motor vehicle collision-related trauma, exacerbations of asthma and chronic obstructive pulmonary disease, myocardial infarction, and mental health challenges.	Consider isolating hospital ventilation systems and enabling recycled air; and ensure staff and patients are provided with well fitted N95 masks if $PM_{2.5} > 30$ mcg/m ³ .	Maximise a patient-centred and creative approach to managing patients who experienced delays in care related to wildfire season.
Climate-related emergency preparedness and management	Assess potential reception centres and relocation sites; consider hospital evacuation scenarios on an inter-agency basis well before wildfire season; consider and manage effects on supply chains, energy, and transport infrastructure; establish and maintain relationships with actors at local, regional, and national levels that will be required to action plans for various contingencies, including tourism operators, commercial entities, and military response units; and ensure shelters are identified and that plans exist to ensure personal and cultural safety of evacuated populations.	Conduct all-hazard vulnerability assessments for health systems; design and conduct drills that simulate patient surge due to smoke and wildfire-related evacuation of health facilities; for hospitals at high risk of evacuation, identify likely receiving hospitals in case of evacuation and work towards inter-operative patient medical records, virtual care capabilities, and trans-jurisdictional licensure for staff to ensure patients can be as well served as possible and evacuated staff have the best chance of being able to ensure continuity of care.	Be aware of staff stress due to increasing and repeated wildfire seasons and be ready to provide relief.	Ensure phased re-entry after an evacuation in which a community is first evaluated for safety, water, sewage, groceries, and the sustainability of health-care delivery.

Table 4: Health service delivery and emergency preparedness and management

for public spending.¹⁰⁸ The creation of cabinet-level inter-ministerial bodies focused on planetary health and disaster response that have strong lines of communication with senior decision makers and access to funds allocated for rapid relief during disasters can help ensure well coordinate responses to wildfires and other natural hazards.

Internationally, the Paris Agreement on Climate Change recognises the necessity for financial contributions by high-income countries to help fund both mitigation and adaptation in low-income and middle-income countries, which have produced less greenhouse gas emissions and yet are seeing many of the first and worst effects.¹⁰⁹ These issues exacerbate health system disparities related to colonialism, which have resulted in net extraction of resources by high-income countries.¹¹⁰ Priority should be given to climate justice-aligned work that seeks to operationalise new funding arrangements related to loss and damage, and mobilise resources including through multilateral development banks, and existing multilateral funds.⁷⁴

Although adaptation funding commitments remain grossly inadequate, fossil fuel subsidies persist.¹¹¹ The health sector must develop a coordinated approach to policy, communications and advocacy since the fossil fuel sector currently has vastly more representatives at international climate negotiations than the health sector, and out-lobbies environmental non-governmental organisations by a ratio of 5:1 at the federal level in Canada.¹¹¹

Driving healthy adaptation necessitates enhanced health sector capacity with regards to policy development and influence, something that requires funding and institutional support from universities and other bodies with an interest in translating evidence into action.¹¹² Health professionals might need to advocate for improved housing or portable air filters for vulnerable patients or for upgraded HVAC systems in public buildings, which can have the additive benefit of reducing viral loads during respiratory virus season. Advancement structures within academia must be realigned to enhance incentives to work towards reaching of real-world effect in service of planetary health beyond data generation and situation analysis.¹¹² The disaster medicine community has been response-focused, which is a key reactive skill set. Their lived experience needs now to be proactively and purposefully funnelled back into policy planning in an era of increasing disasters.

We must break down silos to save lives. Through this Review we hope to have provided a briefing for front-line health professionals on the major health and health systems challenges associated with wildfires, and a framework to inform their response. We envision this work as an initial contribution to help close the gap between need and delivery and contribute to the development of a validated tool to inform a healthy response to extreme wildfires.

Conclusions

Severe wildfires affect physical and mental health of people both at the site of fire and in distant places. Temperature and precipitation projections predict an escalating global wildfire threat that demands proactive, multi-sectoral efforts to protect public health. Actors with a role in wildfire response must collaborate across borders, sectors, and skillsets to evaluate vulnerabilities, fortify infrastructure, integrate disaster planning, train workforces, accelerate research, provide mental health care, engage communities, and increase adaptation funding. Communities should enhance social cohesion to boost resilience. Health systems should prepare facilities to enhance readiness, partner with communities, and advise at-risk patients. Academic institutions should prioritise climate change in health curricula (eg in medical school, nursing, public health, and health-care administration) and drive solution-focused research, policy development, communications, and advocacy. Governments must integrate climate considerations into health policy and planning. Global leaders must support climate adaptation in affected nations. Wildfires will worsen, but collective action can mitigate their harms. All of society must work creatively and courageously to conquer the wildfire threat and safeguard our future.

Contributors

AJH and CH led the project, provided oversight, reviewed the literature, wrote the first draft, and coordinated edits. CS, JR, EE, SH, JT, and GC contributed content and edits.

Declaration of interests

We declare no competing interests.

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