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Evidence Review:

Use of evacuation to protect public health during wildfire smoke events

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Key points

- The single peer-reviewed evaluation of evacuation during a wildfire smoke event found that providing portable HEPA filters was more effective than evacuation at reducing respiratory symptoms among those with a history of cardiopulmonary illness. In this case, the evacuation occurred after the main smoke event.
- Although there is limited peer-reviewed evidence of association between various health outcomes and evacuation, the current evidence does provide limited understanding of the potential harms of evacuation. Previous evacuations have been associated with: increased morbidity and mortality among nursing home residents, infectious diseases among those residing in shelters, exacerbation of mental illness in adults, and poor mental health among children.
- Many current wildfire smoke response guidelines recommend that decision-makers consider evacuation to protect from smoke hazard, but some guidelines reserve evacuation for protection from fire hazard only.
- Those wildfire smoke response guidelines that do consider evacuation to protect from smoke exposure recommend it only for those who are vulnerable rather than for entire populations. Vulnerable individuals include both those who are particularly susceptible to health effects from smoke exposure and those requiring special assistance for evacuation.
- In current guidelines, the main trigger for consideration of evacuation is particulate matter concentration (either monitored or visual acuity).

Evidence Gaps

- There is little evidence on the effectiveness of evacuation to prevent adverse health effects of wildfire smoke exposure in the peer-reviewed and grey literature. Careful evaluation of future wildfire smoke evacuations is needed
- Practical knowledge about wildfire smoke evacuations may exist among experienced practitioners (e.g. emergency managers and public health officials). Case studies could be used to identify commonalities among past evacuations and to draw out lessons for future evacuations.
- A blend of targeted mandatory, voluntary and personal evacuation, air shelters and other measures may be used to reduce smoke exposures across a population. However, it is not clear how best to combine these to maximize benefits and minimize harm. Evaluation of future wildfire smoke response efforts could address this key gap.
- It is not clear how best to incorporate additional smoke surveillance methods into decisions to trigger or rescind evacuation orders (e.g. remote sensing, smoke proxies, smoke forecasting).
- It is not currently clear how best to incorporate health outcomes surveillance into evacuation decisions and real-time evaluation and response cycles. However, near-real-time surveillance of health outcomes is already available in some jurisdictions and being developed in others.

Considerations

The decision of who, *how best* and *when* to evacuate is challenging. Evacuation decisions should be based on clear public health objectives and be designed to optimise health protection and minimize harms. Clear public health objectives are particularly relevant for evacuation decisions because of the risks and losses associated with them. Objectives help navigate decisions about who to evacuate, when to evacuate and how.

Evacuation decisions can be part of a blend of interventions for the general population and subpopulations with particular sensitivities and vulnerabilities. For example a given wildfire smoke situation may require the provision of community clean air shelters for some population subgroups and the simultaneous evacuation of other subgroups. Furthermore a particular evacuation effort may progress from partial to mandatory evacuation as smoke conditions worsen. The evidence of effectiveness of evacuation is limited, and identifies a number of potential harms. Thus the decision to evacuate must be made cautiously based on the specific circumstances. This review provides insight into circumstances that favour evacuation and those that do not.

Factors that favour evacuation

- A severe smoke hazard with population exposure that is expected to last for several days.
- Wildfire smoke that is unusually toxic, for example, due to fuel contaminated with hazardous chemicals.
- An exposed population subgroup that is particularly sensitive to smoke health effects (e.g. pre-existing respiratory or cardiovascular disease, children, elderly, pregnant women).
- Detection of smoke-related health impacts through health surveillance or other means.

Factors that make evacuation a less favourable option

- Milder wildfire smoke conditions: low concentration, short duration forecasted and not contaminated with hazardous materials.
- Exposed population that is not particularly sensitive or vulnerable (as described above) .
- Effective personal and/or community air shelters capable of providing filtered air to those who need it.
- High logistical, cost and other barriers to evacuation.

Ways to improve the success of evacuation

- Population subgroups that are vulnerable because they require special care to evacuate (e.g. people with mobility impairment), enhanced care (e.g. those in long term care facilities) or healthcare that cannot be provided in the community (e.g. dialysis patients) should be evacuated early.
- Address factors that may hinder people's willingness to evacuate (e.g. financial barriers, evacuation of pets and livestock et cetera).
- Ensure adequate capacity and funding to safely complete an evacuation in a timely manner.
- Conduct the evacuation earlier in situations where the only egress route(s) are currently passable, but may later be threatened by fire or smoke.
- Coordinate plans for evacuation due to smoke and evacuation due to fire.

1. Introduction

Wildfires at or near the urban–wilderness interface can pose great risk to human health and safety. Immediate emergency response is often focused on protecting individuals from fire hazard. However, a growing body of evidence demonstrates that exposure to wildfire smoke poses a health risk and that certain subpopulations may be particularly vulnerable (refer to *Health Effects of Smoke* in this series). This has led to increasing effort to protect the public from wildfire smoke exposures.

Evacuation is the urgent removal of individuals from an area, such as a building or a community, when there is an immediate risk to human health and safety. There are five stages of evacuation; decision to evacuate, warning, withdrawal, shelter, and return (1). There are three general types of evacuation: tactical, voluntary, and mandatory (2). Tactical evacuations are typically issued to quickly remove people from an area for operational requirements and are beyond the scope of this review. Voluntary evacuations occur before or during the time that the public is warned that mandatory evacuation of an area may be necessary. Mandatory evacuations occur once a population is immediately threatened by disaster and may be enforced by police. Evacuation may be partial, involving a subgroup of the population or complete, involving the entire population.

While an advancing flame front of an interface fire is of significant concern for human health and safety, smoke from wildfires can travel large distances and affect the health of communities at a distance from the originating fire (3). Globally, an average of 340,000 premature deaths occur every year that can be attributed to fine particulate matter from landscape fires, which include wildfires (4). Air pollution originating from wildfires has prompted the declaration of local states of emergency (5), and while evacuations for to wildfire smoke alone are less frequent, they do occur (6). In Canada wildfires typically affect smaller, remote communities at a higher frequency than more densely populated areas in the southernmost parts of the country in contrast to the US and Australia where there is more overlap between urban and wildfire prone areas (6). Between 1980 and 2007, 19% of wildfire evacuation events (n~100) and 10% of wildfire evacuees (n~21,000) in Canada were prompted by concerns about smoke. However, one-third of wildfire evacuations events overall and three-quarters of wildfire smoke prompted evacuation events occurred among indigenous communities (6). This indicates that wildfires disproportionately affect Canada's indigenous peoples (6). This inequity may be a result of the overlap between those communities and high-risk wildfire areas (6).

The decision to evacuate is complex and challenging. In wildfire smoke situations, public health professionals need to determine whether evacuation is the most appropriate intervention to protect health. There is limited understanding of the risks and benefits of evacuation. Protection from wildfire smoke may be achieved through a number of less intensive measures such as event cancellation, recommendations to stay indoors and use of personal or community clean air shelters (each reviewed in separate sections of this series). Thus the benefits and harms of evacuation must be weighed against those of other options.

Evacuations are inherently difficult to evaluate because they are unpredictable, urgent and disruptive. Focus of evacuations is, and should be, immediate protection of populations, rather than evaluation. Furthermore, the episodic nature of wildfires and relative rarity of evacuation as a protective measure against smoke leads to few situations to evaluate. Therefore, most studies of evacuation are not wildfire smoke related and most evacuations for wildfire smoke are not evaluated. In general, evaluations of evacuations tend to be retrospective rather than prospective and cross-sectional rather than longitudinal. There is no 'standard' evacuation procedure and often no useful comparison group. In addition, depending on the scope and type of emergency and capacity for research, data collection may

involve sacrificing precision for validity, and generalisability for situational awareness. Therefore, the generalizability of findings in the literature is limited.

2. Objective

The purpose of this review is (1) to assess current evidence for the effectiveness of evacuation in protecting the public from wildfire smoke, (2) to review guidance on evacuation in current guidelines for response to wildfire smoke and (3) to highlight considerations for evacuation in planning and response to wildfire smoke situations. The intention is to provide current evidence about whether to evacuate, and if so, who to evacuate. Guidance on how to evacuate is beyond the scope of this review.

3. Methodology

A literature search was conducted on scientific and grey literature sources. Sources searched include PubMed, Summon (University of British Columbia library), and Google Scholar. The search was conducted from late October, 2013 through March, 2014. Key words and search strategies used in the search are in Table 1. The titles and abstracts for articles returned in the search were examined further to determine if they were pertinent to evacuations for wildfire smoke. In addition, bibliographies were scanned for additional resources based on pertinent in-text references. Targeted queries were also made to follow and develop ideas or identify relevant documents based on discussions with experts in the field.

Table 1: Search Strategy and Results

Search	Database	Search Term(s)	Term Type	Articles to Consider for Inclusion
Evacuation for wildfire smoke	PubMed	(((((((wildfire*) OR bush) OR fire*) OR forest fire) OR brush fire) OR wild land fire) AND smoke AND evacuation)	Text Term	2
Evacuation for wildfire smoke	UBC Library (Summon)	(smoke - adverse effects OR evacuation OR smoke) AND (fires OR wildfire OR wild land fire OR wildfires OR forest & brush fires OR forest fires OR fire)	Subject Terms	9
Evacuation for wildfire smoke	Google Scholar	"smoke" "evacuation" "wildfire" OR "forest fire" OR "brush fire" OR "wild land fire" OR "bush fire"	--	5
Harms and benefits of evacuation	PubMed	(health impacts) AND (evacuation)	Text Term	6
Guidelines	UBC EBSCOhost Google, Google Books, Google Scholar, manual search of firesmoke and environmental health websites Search of websites of public health agencies in Canada, US states and other countries susceptible to wildfires	(smoke OR firesmoke OR “air pollution” OR “air quality”) AND (fire OR wildfire OR bushfire OR brushfire) AND “public health” AND (guidelines OR guide OR guidebook OR guidance OR recommendations OR procedures)	--	--

4. Results

4.1. Effectiveness of evacuation for wildfire smoke

A single study evaluated the effectiveness of evacuation during a wildfire smoke event. Mott et al 2002 (7) conducted an observational study of a severe wildfire smoke event to evaluate the effectiveness of various interventions in reducing health effects. The 1999 wildfire burned for over two months producing over two weeks of hazardous smoke for the indigenous population residing on the Hoopa Valley National Indian Reserve in Northern California. Four interventions were studied: distribution of filtered and non-filtered masks, public service announcements advising personal actions to take in order to reduce exposure, distribution of portable high-efficiency particulate air (HEPA) cleaners, and provision of vouchers for hotel services in nearby towns to facilitate evacuation. All interventions were provided at no cost to the population. Distribution of HEPA cleaners and hotel vouchers were prioritised for people who were vulnerable to the health effects of smoke. Vulnerable individuals were identified as those who experienced adverse health effects (cough, chest pain, and difficulty breathing) from smoke and those who had been treated for a cardiopulmonary disease within the previous year. Evacuation did not emerge as an intervention that significantly reduced lower respiratory tract symptoms. In addition, Mott et al 2002 concluded that at home interventions, such as use of a HEPA filter, were more effective than evacuation in preventing adverse health effects among vulnerable people. It was thought that these findings were related to the unpredictability of smoke exposures and because only 17% of evacuees were away during the period of highest smoke concentrations.

4.2. Health impacts of evacuation

A brief, non-exhaustive summary of health impacts associated with evacuation documented in the scientific literature is presented in Table 2. While none of the studies outlined in Table 2 are related to evacuations for wildfire smoke, Tally et al 2013 (8) documents the findings of a cross-sectional survey of San Diego Mental Health Services clients gauging the impacts of the 2007 San Diego wildfires on mental health status as well as impacts on factors influencing mental health. The survey captured evacuees, individuals living in the evacuation area who did not evacuate, and individuals not living in the evacuation area. Results of the survey indicated that evacuees were most impacted by the fires. Evacuees were most likely to report seeking additional mental health services, interruption of regular health services, increased anxiety, fear, and depression, and confusion about when or whether to evacuate. Both evacuees and non-evacuees from the evacuation area reported increased difficulty taking and obtaining medications, and trouble finding adequate information about the fires. This study is limited in that individuals whose mental health may have been impacted by the wildfires to the point where acute care interventions were required may not have been captured in the survey. In addition, many individuals with mental illness live successful and productive lives in the community and a “large number of clients” surveyed in this particular study reported little or no effects from the fires. However, despite a lack of generalisabilty, the findings of this study may serve as an indicator of vulnerability to adverse health outcomes related to evacuation situations in general among individuals with less severe manifestations of mental illness or those who, for whatever reason, may be more resilient.

Kinra et al 2005 (9) documented the results of a cross-sectional health survey of a population exposed to chemical smoke. The target population were all people living in an area exposed to contaminated smoke originating from a fire in a nearby plastics factory. Early in the incident, a decision was made to evacuate residents from the affected area. However, after reviewing this decision it was subsequently decided to halt evacuation and advise residents to take shelter in their homes. A questionnaire was administered to

the target population in order to gauge the occurrence and persistence of health symptoms in addition to describing demographics, health status, risk factors, and location of residence of members of the population during and shortly after the event. Symptoms included in the survey were runny eyes, swollen eyelids, sore throat or nose, shortness of breath, cough, skin rash, skin burns, nausea, vomiting, abdominal pain, diarrhoea, fever, wheezing or asthma, palpitations, headache, light-headedness, and blurred vision. Authors noted that during the two weeks following the event, health effects were more commonly reported among evacuees relative to those who sheltered-in-place. However, proxy measures of exposure prior to intervention was found to be significantly higher among evacuated residents relative to sheltered residents but did not contribute to the odds of experiencing exposure-related symptoms. Limitations of this study include a relatively low response rate (63%), an inability to quantify differences in exposure among evacuated and non-evacuates individuals, and an inability to differentiate between physical effects of smoke exposure, psychological effects of smoke exposure, or psychological impacts of evacuation. However, the population of evacuees and non-evacuees all resided in the same area, and the decision to evacuate individuals was not based on exposures or vulnerabilities. Therefore, it remains possible that increased self-reported health effects were reflective of psychological impacts of evacuation or exposure during evacuation, in addition to measurement or sampling bias, or differences in exposure not related to the process of evacuation. These results are significant to evacuation for fire smoke given that they indicate that there may be increased risk of exposure or psychological impacts influencing the manifestation of symptoms among evacuees shortly after evacuation.

Dosa et al, 2012 (10) documented findings from a case-cohort study which examined 30 and 90-day mortality and hospitalisation rates among nursing home residents evacuated ahead of Hurricanes Katrina, Rita, Gustav, and Ike compared to residents of the same nursing homes during the same time of year during the two years prior to the hurricane. The study found that there were 7.6 additional deaths per 1000 residents at 30 days and 15.9 additional deaths per 1000 residents at 90 days among evacuees. Similarly, there were 23.9 extra hospitalisations per 1000 residents at 30 days, and 14.9 extra hospitalisations per 1000 residents at 90 days among evacuated nursing home residents. This study did not take into account for some potential confounders, such as disruptions in health services because of the hurricanes, effectively rendering any interpretation of the results as being associated with evacuation alone inappropriate. However, the sample sizes for both cohorts were very large adding precision to the estimates. These results are pertinent to evacuations for wildfire smoke given that it is possible that there is a link between increased morbidity and mortality, and evacuation among nursing home residents.

Kawano et al 2014 (11) reported findings from a retrospective cohort study which followed a population of evacuees during their stay in reception centres after the 2011 earthquake and tsunami in Japan. Researchers accessed medical records from evacuees who visited medical clinics in the reception centres during evacuation to estimate the occurrence of various infectious diseases. Researchers identified outbreaks of acute respiratory infections (mean cumulative incidence: 13.1 person-days) and acute gastroenteritis among evacuees (mean cumulative incidence: 1.6 person-days), but no cases of tetanus, pertussis, measles, scabies, or acute jaundice syndrome. While this study is limited to individuals who visited the on-site medical clinic while staying at a reception centre, the study population may serve as a good indication of what was occurring in the total population of evacuees residing in reception centres included in the study during evacuation. These results are applicable to evacuations for wildfire smoke given that overcrowding in reception centres may encourage infectious disease transmission among evacuees.

The methods of other studies on the impacts of evacuation identified in this review pertained to interviews, surveys, and chart reviews. These studies provide valuable insight into the lived experiences of those who have been evacuated under a variety of circumstances. Heppenstall et al 2013 (12) used a general inductive approach to examine the contents of interviews conducted with residential care facility residents evacuated to reception centres after the 2011 Christchurch Earthquake as well as their caregivers. Results from this study identified increased anxiety and cognitive decline among residents, despite their overall resilience. Cacchione et al 2011 (13) describes results of chart reviews among 17 long term care residents evacuated for several days due to a severe summer storm. Results identified increased confusion that was suggestive of delirium among residents during the two weeks following evacuation. Slone et al 2009 (14) studied psychological distress among children from families subject to forcible evacuation as a result of geopolitical conflict. Participants were identified by convenience sampling and both mothers and children were interviewed by researchers. Results indicated that there was an increase in evacuation-related obsessive compulsive, depressive and anxiety symptoms among children included in the study. These symptoms were assessed to be evacuation-related, occurring in addition to psychiatric symptoms associated with the geopolitical situation. The results of these studies indicate that evacuation can result in harm among certain members of the population, specifically children and the elderly. Given that children and the elderly are among those considered to be most vulnerable to fire smoke, results of these studies become more pertinent in weighing risks and benefits for smoke prompted evacuation.

No studies were identified in the literature that assessed potential benefits of evacuation. However, it can be assumed that benefits of appropriately conducted evacuations for smoke events include a reduction or elimination of smoke exposure, and potential of placing individuals out of danger from the wildfire itself. In addition, no articles returned evaluated evacuations specifically. This information may be found in sources that are not readily available to the public.

Taken together, the studies identified in this review illustrate that evacuation is not without harm. Previous evacuations have been associated with: increased morbidity and mortality among nursing home residents, infectious diseases among those residing in shelters, exacerbation of mental illness in adults, and poor mental health among children. Given the risk of harm to individuals as a result of evacuation, it is important to weigh evacuation-related harm against the harm of staying in the area during a fire smoke event.

Table 2: Health effects reported in evacuation situations.

Article	Location	Disaster Type	Study Type	Population	Findings
Tally, Levack, Sarkin, Gilmer, & Groessl 2013 (8)	United States	Wildfire	Cross-sectional survey	Clients of San Diego County Mental Health Services during a 2-week survey period in the fall of 2007. Included individuals who were evacuated from the 2007 San Diego Wildfires, individuals who lived in the evacuation area but did not evacuate, and those not living in the evacuation area.	Evacuees: ▪ More likely to seek additional mental health services due to fire ▪ Interruption of regular mental health services ▪ Increased stress, anxiety, fear and depression related to the fires ▪ Confusion about when or whether to evacuate ▪ Trouble finding adequate information about the fires Both evacuees and non-evacuees from evacuation area: ▪ Increased difficulty taking and obtaining medications during the fires
Kinra, et al. 2005 (9)	England	Airborne chemical release	Cross-sectional survey	Population residing in the area surrounding a fire in an industrial park	Observed increased health effects among evacuated population in comparison with the sheltered population. Evacuated population had higher exposures prior to intervention than sheltered population. Increase in health effects lasted 2 weeks or less
Dosa, et al. 2012 (10)	United States	Hurricane	Case-cohort	Nursing home residents	Reported increased morbidity and mortality among residents who were exposed to hurricanes and evacuated relative to residents not exposed to hurricanes and who were not evacuated.
Kawano, Hasegawa, Watase, Morita, & Yamamura 2014 (11)	Japan	Tsunami and earthquake	Retrospective cohort	Population who visited shelter medical clinics during evacuation	Reported the occurrence of outbreaks of acute respiratory infection (cumulative incidence: 13.1 person-days) and acute gastroenteritis (cumulative incidence: 1.6 person-days) in evacuation shelters. No cases of tetanus, pertussis, measles, scabies, or acute jaundice syndrome were reported.

Article	Location	Disaster Type	Study Type	Population	Findings
Heppenstall, Wilkinson, Hanger, Dhanak, & Keeling 2013 (12)	New Zealand	Earthquake	Interview	Elderly residing in residential care facilities and caregivers	Areas of concern were identified as being anxiety, cognitive decline, and communication difficulties. Personal attitudes, life experiences, enhanced family support, and social supports were found to enhance resiliency.
Cacchione, Willoughby, Langan, & Culp 2011 (13)	United States	Severe summer storm	Chart reviews	Elderly residing in long-term care facility	Noted increased confusion/delirium among evacuees relative to what was documented previously.
Slone, Shoshani, & Paltieli 2009 (14)	Gaza Strip	Geopolitical conflict	Interview	Children from families forcibly evacuated from Jewish settlements in the Gaza Strip	Noted evacuation-related obsessive-compulsive, depressive, and anxiety symptoms. These symptoms were determined to be in addition to psychiatric symptoms determined to be related to conflict

4.3. Considerations for wildfire smoke prompted evacuations

There are a number of considerations that need to be taken into account when deciding whether to evacuate. Considerations pertinent to evacuation in wildfire situations identified in peer-reviewed and grey literature sources are briefly summarised in Table A-1 in the appendix and discussed below.

4.3.1. Objectives of evacuation

The public health objectives of a response will inform evacuation decisions. For example, objectives could variously be: to decrease the number of susceptible individuals exposed, to protect the most susceptible from potentially fatal smoke exposures, or to evacuate those with special requirements in order to facilitate a potential future evacuation. Each of these objectives may lead to different conclusions about whether to evacuate or provide clean air shelters, who to evacuate and when.

4.3.2. Evacuation versus providing clean air shelters (CASs)

Home or community clean air shelters (HCAS or CCAS) may provide sufficient protection from wildfire smoke in certain situations (refer to review on *Air Shelters*) but their relative effectiveness has rarely been evaluated. The single such evaluation in a wildfire smoke situation on the Hoopa Valley National Indian Reserve, Mott et al 2002 (7) found that providing portable HEPA filters was more effective than evacuation at reducing symptoms among those with a history of cardiopulmonary symptoms or disease.

The process of deciding whether or not to evacuate during a typical wildfire smoke event is a decision between clean air shelters in situ or removal of populations to clean air elsewhere. Logistical and situational concerns will largely inform the appropriate blend of clean air shelters and evacuation. Sheltering in the community requires the capacity to provide clean air shelters, provide adequate filtration in institutional and health care facilities, and portable air filtration units for the duration of the

event. Thus, evacuation may be appropriate when the capacity for air filtration for the community or sensitive sub-groups is not possible for the foreseeable smoke event, or when filtration is insufficient to clean the air (e.g. contaminated smoke). Clean air shelters may be more appropriate when the financial, logistical, and other barriers to evacuation are high.

4.3.3. Evacuation of vulnerable populations

Wildfire smoke poses a risk to human health and wellbeing, specifically among vulnerable populations. Some jurisdictions, such as Manitoba and Northern Saskatchewan, recommend considering the evacuation of sensitive populations only during the worst air quality events (15, 16). People vulnerable to the health effects of wildfire smoke include individuals with respiratory and cardiovascular disease, unborn children, infants and children and the elderly (for further information on this please refer to evidence review *Health Effects*).

Prioritisation for evacuation is not solely based on vulnerabilities to the health effects of smoke. Some guidelines require plans to include individuals who may be more difficult to evacuate in an emergency or individuals for whom continuity of necessary medical or personal care cannot be guaranteed during an emergency (15, 16). This includes individuals with mobility issues, or people requiring special and supportive care, such as individuals in acute care facilities, residing in institutions, relying on home care services, or people on dialysis (15, 16). Planning for evacuation, including appropriate means of transport based on medical and care needs of these individuals is in important consideration as well (15).

4.3.3.1. Factors that affect response to evacuation orders

Evacuation orders are not always adhered to by all members of a population. A number of different factors can influence whether or not people decide to evacuate. Generally, for members of the public to comply with desired actions in emergency situations, they must: receive and be able to understand information pertaining to the hazard; understand that the information is relevant to them, and that action is required to avoid harm; and know the appropriate actions to take and be able to undertake them (17).

There is a lack of information about factors influencing evacuation specifically for wildfire smoke. Mott et al 2002 (7) does report financial and economic barriers to evacuation for wildfire smoke: 45% of study participants cited an inability to miss work while 12% responded economic constraints as being behind the decision not to evacuate during the fire smoke event. Mozumber et al, 2008 (18) is a peer-reviewed literature source that documents the findings of a cross sectional survey of intended evacuation behaviour due to wildfire risks. Households surveyed in this study come from a high-risk wildfire area in New Mexico. Limitations of this study include a very low response rate (25%). One particular strength however, was that the area included in the study had not experienced a wildfire in recent history. The study found that people are more likely to evacuate under a mandatory evacuation order (89%) as opposed to a voluntary evacuation order (57%) in wildfire situations. Intention to evacuate under both mandatory and voluntary orders are influenced by risk-perception; people who are more concerned that their home may be in danger of being damaged or destroyed by wildfire are more likely to evacuate. Other factors that were found to significantly influence were: ownership of pets or livestock - these individuals are less likely to evacuate under a voluntary order; ownership of livestock – people who own livestock are less likely to evacuate under a mandatory evacuation order; evacuation destination – staying in a motel or hotel, or with family or friends increases the likelihood of adhering to mandatory evacuation orders versus staying in a public shelter; and education and income – level of concern may

be lower among those with lower income or lower education levels, thereby reducing the likelihood of evacuation.

4.3.3.2. When to rescind evacuation orders

In general, evacuation orders are rescinded when it has been determined that the area is safe for individuals to return home (19, 20). Considerations for allowing or organising the return of evacuees to their community include: limited on-going risk from smoke and fire, community capacity to manage people with special health care needs in their home community, availability of basic services (i.e. drinking water, sewer, transportation infrastructure), lack of on-going risks to safety (e.g. from damage to buildings, ash deposition et cetera), and minimal risk in transporting individuals home (19, 20).

4.3.3.3. Use of environmental and health information in evacuation decisions

Particulate matter thresholds are used to guide the decision to evacuate in many current guidelines for public health response to wildfire smoke. Lipsett and Materna 2008 (21) recommend that officials consider evacuating sensitive populations when air quality conditions are 'hazardous' as defined using the 24-hour $PM_{2.5}$ average concentrations defined by the Air Quality Index (AQI; 250.5 ug/m^3). PM_{10} 24-hour average concentrations and 1-3 hour and 8-hour $PM_{2.5}$ and PM_{10} averages are derived from this 24-hour average. These are quality thresholds are repeated in several other guidelines either verbatim (New Mexico (22)), or with slight variation based on forecasted duration of smoke. Guidance from Northern Saskatchewan (16) and Manitoba (15) suggests that evacuation be considered using the same 1-3 hour average $PM_{2.5}$, if "conditions are forecasted to remain heavy for some time". Guidance from Oregon (23) recommends self0evacuation if the forecasted duration is shorter (24-72 hours) and evacuation when duration is longer (>72 hours). In addition to monitored PM, most of these guidelines recommend considering evacuation when visibility is less than one kilometre (Canadian guidelines) or one mile (American guidelines). We are not aware of any evaluation of the use of air quality thresholds derived from studies of urban PM (such as the AQI) in wildfire smoke situations. The limitations of these thresholds should be explored and could be an important consideration in smoke response decisions.

Other jurisdictions, such as the Government of Western Australia and the World Health Organisation recommend sheltering in place during smoke events and evacuating only when individuals are threatened by the fires themselves and reserve the decision to evacuate for smoke to be decided on a "case-by-case" basis (24, 25).

Guidance for the general public may not include evacuation. For example, the states of Alaska and Arizona, do not mention evacuation in their public website, instead they recommend individual actions to reduce personal exposures at varying air quality thresholds (26, 27).

Other measures of current and potential smokiness may enhance information for public health and emergency management decision-makers (more detail is provided in the review *Smoke Surveillance*). Air quality may be estimated using remote sensing and air quality modeling, in addition to monitors and visual acuity. In the absence of any air quality measure, smokiness may be assessed using a proxy, such as number and proximity of fires.

Duration of smoke is a key consideration in evacuation decisions, yet one of the most difficult to assess. Evacuation is a major undertaking that can be rendered useless if the smoke clears. The importance of evacuation timing is evident in the evaluation of the evacuation of the Hoopa Valley National Indian Reserve which occurred after the main smoke event and was not found to protect sensitive groups (Mott 2002). Systems to forecast wildfire smoke have been developed and evaluated (e.g. BlueSky (28)),

and may prove useful in forecasting anticipated duration of smoke. While information about smoke duration is critical when deciding to start evacuation processes or rescind evacuation orders, it is not clear how best to use such information to inform decisions.

Wildfire smoke can vary in toxicity, for example due to forest composition (Dokas et al (29), refer to review on *Wildfire Smoke*), and wildfires may also burn into anthropogenic toxins such as uranium mines (30), and plastics warehouses or landfills (31). Therefore toxicity of wildfire smoke should be part of evacuation decisions.

Surveillance of health outcomes in real-time could provide critical information to inform evacuation decisions. Health effects may be assessed using a system established for surveillance of wildfire smoke effects, adapting another system that uses respiratory outcomes (e.g. influenza surveillance system) or through active surveillance methods (e.g. call outs to physicians, chart review). A number of these systems are in place, and preliminary studies demonstrate associations between several health outcomes and wildfire smoke (Yao et al 2013 (32), Elliott et al 2012 (33), refer to review on *Health Surveillance* for further information). However their role and effectiveness in wildfire smoke situations has yet to be thoroughly evaluated.

5. Summary

Evacuation the can be used to urgently remove individuals from a community in order to protect them from exposure to wildfire smoke. Evacuation may be voluntary or mandatory, or may begin as a voluntary measure and evolve into a mandatory order. Evacuation may be partial, involving a subgroup of the population or complete, involving the entire population.

There are many possible interventions that can be used to reduce wildfire smoke exposure. The decision of *how best* and *when* to use evacuation is largely a decision about the optimal blend of interventions for the general population and subpopulations with particular sensitivities and vulnerabilities. For example a given wildfire smoke situation may require the provision of community clean air shelters for some population subgroups and the simultaneous evacuation of other subgroups to a location with cleaner air. Furthermore a particular evacuation effort may progress from partial to mandatory evacuation as smoke conditions worsen. The evidence of effectiveness of evacuation is limited, and any individual evacuation decision will be dictated by the specific circumstances. This review provides insight into circumstances that favour evacuation and those that do not. Specific considerations are provided at the start of this document. A list of general considerations and elements of evacuation plans are provided in Tables A-1 and A-2 in the appendix.

Appendix

Table A-1: General considerations for decisions related to evacuation in wildfire situations.

Article	Location	Population	Consideration(s)	Article Type	Study Type	Consideration Type
Yao et al. 2013 (32)	British Columbia, Canada	Residents of British Columbia	Use of health surveillance to provide situational awareness	Peer-reviewed	Environmental health surveillance	Situational awareness
Sakiyama 2013 (28)	British Columbia, Canada	n/a	Use of air quality forecasting data to provide situational awareness	Grey literature	n/a	Situational awareness
Dokas, Statheropoulos, & Karma 2007 (29)	n/a	n/a	Toxicity of smoke	Peer-reviewed	Development of conceptual framework for risk assessment	Situational awareness
Mozumder, Raheem, Talberth, & Berrens 2008 (18)	New Mexico, United States	Residents of the East Mountain, NM area	Factors related to adherence to evacuation orders among members of the affected population	Peer-reviewed	Cross-sectional survey	Adherence to evacuation orders
Government of Canada 2007 (34) Commonwealth of Australia 2009 (35) Federal Emergency Management Agency 2013 (36)	Canada, United States, and Australia	Canadians, Americans, Australians	Responsibility for emergency preparedness and disaster management is placed on provinces/states/territories and local authorities. There are emergency planning and management roles and responsibilities at national levels, particularly for situations that are counted as being under federal jurisdiction or where regional resources are overwhelmed and assistance is needed. Such plans generally do not preclude involvement of local and regional emergency plans.	Grey literature	n/a	Planning

Article	Location	Population	Consideration(s)	Article Type	Study Type	Consideration Type
Government of Canada 2007 (34) Emergency Management BC 2011 (19) Emergency Management Ontario 2013(20) National Council Congress of American Indians (37)	Canada and United States	Indigenous populations	Canada: Aboriginal Affairs and Northern Development Canada is responsible for emergency preparedness and disaster management on non-treaty First Nations and Inuit lands, unless there have been arrangements to incorporate indigenous communities into provincial plans. Indigenous communities are responsible for their own emergency preparedness planning and disaster management where included in treaties. Federal assistance can be provided when local resources are overwhelmed. United States: Tribal governments have a broad role in emergency management. However, federal assistance can be provided when local resources are overwhelmed.	Grey literature	n/a	Planning
Emergency Management BC 2011 (19)			Hazard, risk, and vulnerability analysis prior to undertaking emergency planning, including the development of an evacuation plan	Grey literature	n/a	Planning
Emergency Management Ontario 2013 (38)			Planning evacuation routes in advance to avoid inadequate infrastructure and prevent crowding	Grey literature	n/a	Planning
Lipsett, & Materna 2008 (21) Manitoba Health 2011 (15) Population Health Unit 2012 (16)			Identification of populations most vulnerable to health effects of smoke exposure, and populations that may be more difficult to evacuate or accommodate in the community during an emergency	Grey literature	n/a	Planning Implementation
Emergency Management Ontario 2013 (38) Emergency Management BC 2011 (19) Manitoba Health 2011 (15) Population Health Unit 2012 (16)			Requirements for ensuring safety of evacuees for the purpose of rescinding evacuation orders and returning evacuees to their homes.	Grey literature	n/a	Implementation

Table A-2: General elements included in an evacuation plan (1, 19, 20, 38)

General elements of an evacuation plan
Identification of who has the legal authority to issue and rescind evacuation orders
Organizations involved in evacuation, including roles and responsibilities
Identifying emergency management structure
Outlining communications protocols, including communications between organizations and communication with the public regarding alerts that evacuation of the area may be warranted, enforcement of evacuation orders, and cancellation of evacuation orders
Consideration of special needs of evacuees
Identification of geographic and demographic concerns, and municipal vulnerabilities;
Identification of resources and assets to be used
Consideration of support for decision making and plans to incorporate real-time information
Provisions for those sheltering in place
Assessment of transportation, including routes and traffic management
Identification of assembly points for transport to reception centers
Identification of evacuation destinations, including reception centers in the community and in neighboring areas
Provisions for the population that will be hosting evacuees; Choice of host population may be particularly relevant for culturally-competent evacuation plans for First Nations and Inuit communities
Provisions for pets/livestock/animals in the area
Provisions for security of evacuated areas
Consideration of requirements for return of evacuees to the impacted area
Processes for regular review and updating of plans

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