



## INTRODUCTION

For several decades now, temperature increases have been observed in Quebec and around the world (IPCC, 2007). In this context, the risks of extreme weather events throughout the globe make ecosystems vulnerable, resulting in adverse effects. Expected impacts include increased drought, heat waves and flooding (IPCC 2007).

A warm, dry climate could therefore cause an increase in forest fires, even in areas of the boreal forest affected by fires during the 21st century (McLaughlin et Percy, 1999). However, there are still some uncertainties regarding these increases.

Forest fires are already a major natural hazard with multiple impacts, particularly on the economy and the environment. It is therefore reasonable to explore their potential health impacts. In doing so, a distinction must be made between two components of these health impacts. First, there are the impacts that occur near the fire site, which consist primarily of fire hazards and poisoning (especially from carbon monoxide). Emergency preparedness officials are responsible for managing these impacts using existing protective measures, such as evacuating areas near fire sites (EPA 2008). Second, and in addition to these local impacts, are those caused by particles from forest fire smoke, which will be discussed in this document.

Particles from forest fires have a measurable impact on public health not only locally, but also in areas hundreds of kilometres away from the combustion source. For example, pollutants from the July 2002 forest fires in northern Quebec were linked to a major increase in the amount of fine particles in Baltimore, an American city over 1000 km from the fire site (Sapkota *et al.*, 2005). Smoke from these fires also affected other cities, including Montreal, where average daily concentrations three times higher than normal were noted, exceeding  $35 \mu\text{g}/\text{m}^3$  with hourly maxima above  $100 \mu\text{g}/\text{m}^3$ . Plumes from combustion sites also affect concentrations of pollutants other than the particles found near fire sites, such as carbon monoxide and atmospheric ozone (Wotawa and Trainer 2000). Concentrations of pollutants (e.g.: ozone) that contribute to urban smog can also increase downwind of and at a great distance from these sites.

A better understanding of the health impacts of forest fire smoke, particularly in relation to particles, that can occur even at extended distances from fire sites (e.g.: in cities where these pollutants already exist because of other emission sources [e.g.: industrial]) is therefore essential.

This fact sheet complements a previous document produced by INSPQ on indicators for the monitoring and surveillance of health problems related to lightning and forest fires (Bustinza *et al.*, 2010). That document proposed a set of health indicators to include in the monitoring and surveillance systems and provided an overview of existing initiatives in Canada in the context of a technological platform for the monitoring and surveillance of climate change and extreme weather events.

This document expands on Bustinza *et al.* (2010), particularly in terms of the epidemiological studies on wildland fires, and focuses specifically on the particles from these types of fires. It reviews epidemiological studies on the health impacts of smoke that are caused by suspended particles from wildland fires (i.e.: forest, brush and other biomass types), but excludes studies on the impacts of exposure to particles from

combustion of fuel (e.g.: for cooking). However, potential interventions for limiting the impacts of fuel combustion particles will be briefly discussed.

## METHODOLOGY

Original epidemiological studies (i.e.: excluding literature reviews) on the health impacts of smoke from wildland fires were researched in the PubMed database using the following keywords: (forest fire OR bushfire OR wildfire) AND (emergency OR hospital OR respir\*).

A total of 110 studies were published in English between January 2001 and April 2012. This number excludes firefighter-focused and experimental studies. 30 scientific publications were retained for analysis. A summary of these publications appears in Table 1 at the end of section 3. Previously published reviews were also consulted for information on the general, contextual and toxicological aspects of wildland fires (WHO 1999, Fowler 2003, Naeher et al., 2007, EPA 2008, Bustinza et al., 2010, Dennekamp and Abramson 2010, ANSES 2012). Lastly, the World Health Organization (WHO), US Environmental Protection Agency (US EPA), Environment Canada and British Columbia Air Quality Web sites were consulted to supplement the information gathered.

## FOREST FIRE SMOKE

Forest fire smoke is a complex mix of carbon dioxide (CO<sub>2</sub>), suspended particles, water vapour, carbon monoxide (CO), organic components such as acrolein and formaldehyde, nitrogen oxides (NO<sub>x</sub>) and various minerals. The composition of this smoke depends on several factors: type of wood or vegetation, humidity, fire temperature, winds and various weather conditions (Mazzoleni *et al.*, 2007).

Because suspended particles can travel over long distances, they are the main pollutants to consider when a population far away from a forest fire site is exposed to the fire's smoke (Weinhold 2011). Very large populations living hundreds of kilometres from the combustion source may be exposed. As stated above, this document investigates the risks associated with exposure to particles from wildland fire plumes. Suspended particles can be categorized based on their median diameter: particles of less than 10 micrometres (PM<sub>10</sub>) and particles of less than 2.5 micrometres (PM<sub>2.5</sub>). Particles from forest fires are generally less than 2.5 micrometres and fine enough to penetrate deep into the lungs.

Gases such as CO, NO<sub>x</sub> and organic components pose a health risk, especially in close proximity to fire sites. Local populations are not the only ones exposed to these contaminants; forestry workers and firefighters are as well. These groups of workers should refer to enacted forest fire directives and protective measures (Bowman and Johnston 2005). These contaminants are less of a concern farther away from the fires because they are quickly destroyed or transformed into fine particles, among other things (Athanasopoulou *et al.*, 2012). Forest fires are also a major contributor to ozone because they release the hydrocarbons and nitrogen oxides that form this compound. Thus, in the lee of the wind of a forest fire, ozone levels can increase even in areas at great distances from the fire (Ward and Smith 2001, Ward *et al.*, 2006).

### **Health impacts of suspended particles in urban air**

Over the past few years, several studies have been conducted on the association between ambient air particles in urban areas and public health (EPA 2009). However, a relatively limited number of studies have assessed the associations between particles from wildland fires and health impacts.

Epidemiological studies conducted in urban areas have reported several health impacts related to short-term exposure (hours, days) to fine particles from multiple sources (e.g.: burned fossil fuels). These health impacts include increased respiratory symptoms (e.g.: coughing, asthma symptoms), decreased lung function, increased use of medical services (e.g. emergency room visits, hospitalizations) and increased respiratory and cardiovascular-related mortality. However, there are still numerous uncertainties regarding these impacts and, according to the US EPA (United States Environmental Protection Agency, 2009), a causal relationship may only exist for the association with cardiovascular-related mortalities. The association with respiratory-related mortalities is plausible, but the lack of consistency between respiratory morbidity studies and particle exposure does not support a causal relationship.

The main symptoms that have sometimes been associated with short-term exposure (a few minutes to a few days) to fine particles are:

- airway irritation (nasal irritation, coughing, throat irritation, sputum);
- wheezing;
- tightness in the chest;
- pain associated with deep breathing;
- difficulty breathing.

### **Impacts of particles from forest fire smoke**

Few toxicological and epidemiological studies specifically investigated the impacts of particles from forest fires. Therefore, little evidence exists to support the hypothesis that the impacts associated with these particles differ from those associated with particles in urban areas emitted from multiple sources.

Some toxicological studies, including those conducted with firefighters, investigated the impacts of exposure to wood smoke through inhalation. The results describe impacts such as immune defence mechanism alteration in the lungs (Naeher *et al.*, 2007). These impacts have major consequences, including decreased infection resistance because of oxidative stress reactions in the lungs (Park *et al.*, 2004) and increased inflammatory response (Swiston *et al.*, 2008), as well as moderate alterations in lung function (Tesfaigzi *et al.*, 2005, Adetona *et al.*, 2011; Jacquin *et al.*, 2011).

The mutagenic nature of wood smoke can also increase the risk of cancer. However, according to the International Agency for Research on Cancer (IARC 2010), there is "limited" evidence that wood combustion emissions cause cancer and "sufficient" evidence that wood smoke extract does (animal studies). Therefore, from a toxicology perspective, there is still not enough knowledge to identify toxic effects based on different biomass types. In all scenarios, the general population would be exposed to smoke for a brief period and the mutagen/cancer risk would be low. However, it could be higher for firefighters and forestry workers.

It is difficult to date to determine whether the toxic potential of particles from wildland fire smoke is higher, lower or the same as for particles in urban air and for which many more studies are available (ANSES 2012). However, most epidemiological studies suggest that particles from wildland fires mainly cause short-term respiratory impacts and few cardiovascular impacts. Still, it is difficult to say whether the respiratory effects of vegetation combustion particles are more pronounced than the effects associated with urban particles.

The next section summarizes the epidemiological studies conducted since 2001 on the impacts of short-term smoke exposure, particularly to suspended particles from wildland fires (see the study selection method above).

## EPIDEMIOLOGICAL STUDIES ON THE IMPACTS OF PARTICLES FROM WILDLAND FIRES

There are two types of epidemiological studies on the impacts of smoke, specifically suspended particles from combustible vegetation fires. Some studies investigated the association between daily particle levels during fires and health events (e.g.: emergency room visits, mortality). These studies report associations by particle increases in  $\mu\text{g}/\text{m}^3$ . The other studies compare health impacts observed during forest fire events with those expected in given periods or control communities. Some of these comparative studies also include analyses conducted by categorizing days or regions based on their particle concentrations rather than associations reported by particulate levels increases. Other studies are more rigorous because the authors used statistical models to control factors such as secular trends in health measures, which can affect the comparisons. However, unlike associative studies between particle levels and health impacts, most comparative studies cannot establish a relationship between health impacts and particulate levels because particulate levels vary depending on the fire episode, as well as the populations in proximity to the fire site. That said, associative studies also have some limitations because the particulate levels are correlated with the levels of other pollutants in the smoke.

### Studies on associations with particulate levels

There are two studies on the association between mortality and particles from wildland fires. One of these studies was conducted in Finland (Hänninen *et al.*, 2008). In 2002, a smoke plume 2500 km long and nearly 1000 km wide extended from the forest fire zone in eastern Europe (Russia, Ukraine) to many Finnish cities. Hänninen *et al.* (2008) reported a non-statistically significant increase in mortalities from all causes in 11 Finnish provinces, with an increase in PM<sub>2.5</sub> from the particles related to the eastern Europe forest fires (with a  $15.7 \mu\text{g}/\text{m}^3$  increase in average particle levels). The association between particles and mortality was similar to that reported for particulate levels in urban areas (EPA 2009). Morgan *et al.* (2010) did not observe an association between cardiovascular and respiratory-related mortality and daily PM<sub>10</sub> levels generated by brush fires in Sydney, Australia (average PM<sub>10</sub> levels  $> 42 \mu\text{g}/\text{m}^3$ ).

There are a few more studies on the association between particles from vegetation combustion and morbidity than there are on mortality. Many of these studies show an association between respiratory-related emergency room visits and hospitalizations and particle levels during vegetation combustion.

Henderson *et al.* (2011) recently investigated the 2003 forest fire season in southeastern British Columbia. They studied the association between daily PM10 levels measured at pollution sampling stations (average of about  $29 \mu\text{g}/\text{m}^3$ ) or estimated with a dispersion model and the number of medical consultations and hospital admissions because of cardiovascular and respiratory problems. Associations were noted with the use of medical services for respiratory problems, but not for cardiovascular problems. Morgan *et al.* (2010) investigated brush fires in Sydney, Australia and, like Henderson *et al.* (2011), noted associations between daily particle levels from vegetation combustion and hospital admissions for respiratory problems, but not for cardiovascular problems. Delfino *et al.* (2009) investigated daily exposure to PM2.5 from forest fires in southern California in 2003. In keeping with the above two studies that suggest that particles from wildland fires cause mainly respiratory impacts, this study reported a more pronounced association between daily exposure and daily hospitalizations for respiratory problems than between daily exposure and daily hospitalizations for cardiovascular problems, and mainly among individuals over the age of 65. (The particle data was estimated with satellite imaging, with average levels for significantly affected areas during fires calculated at  $90 \mu\text{g}/\text{m}^3$ .)

Several other studies conducted in Australia mention associations between daily PM10 levels and emergency room visits and hospitalizations for respiratory problems (e.g.: asthma and chronic obstructive pulmonary diseases) during brush fires (Tham *et al.*, 2009; Johnston *et al.*, 2006–2007, Hanigan *et al.*, 2008). Cançado *et al.* (2006) and Arbex *et al.* (2007) also reported positive associations between suspended particulate levels during sugar cane burning periods and hospital admissions for respiratory problems, whereas Arbex *et al.* (2010) reported increases in hospitalizations for hypertension. Yadav *et al.* (2003) noted correlations between the number of hospital visits for respiratory diseases and PM-10 levels during forest fire events in Borneo. However, some discrepancies were noted in the results of studies on the association between morbidity and particles from wildland fires. For example, Hanigan *et al.* (2008) and Johnston *et al.* (2007) noted a sometimes non-statistically significant decrease in infections and medical visits for cardiovascular problems with the increase in PM10 during the brush fire periods studied.

### **Comparative studies of health impacts during particulate events vs. health impacts during given periods or in control communities**

Evidence of increased mortalities during forest fire events versus mortalities noted in given periods or control communities are currently inconclusive. Johnston *et al.* (2011) reported increases in mortality from all causes, including cardiovascular and respiratory problems (from 2 to 9%), but they proved non-statistically significant, especially on the day after the extreme dust events in Australia (mostly brush fires with PM10 levels  $> 47 \mu\text{g}/\text{m}^3$ ). Analitis *et al.* (2012) observed daily mortality increases of over 50% in Athens on days when there were major fires ( $> 30\,000 \text{ km}^2$ ) compared with days when there were no fires. These increases were more substantial for respiratory-related mortalities. However, the addition of black smoke measurements in the statistical models (generalized additive models) had no effect on forest fire impacts. According to the authors, this suggests that the particles may not be associated with the increased number of deaths noted. The authors suggest that other factors may explain the increased mortalities, such as post-traumatic stress and the population's state of panic on fire days. Vedal *et al.* (2006) noted an increase in cardiovascular and respiratory-related mortalities in Denver, Colorado, after particles were emitted from forest fires in 2002, compared with the mortalities recorded during a control period. However, mortality increases were also observed in other cities not exposed to smoke during this period. The authors therefore ruled out an association between a noted

increase in mortalities and an increase in levels of particles from smoke. They hypothesize that the temperature increase during these fires could be a more plausible causal factor. Lastly, Sastry *et al.* (2002) report an increase in cardiovascular-related deaths in people between the ages of 65 and 74 during a fire event and a non-statistically significant increase in respiratory-related deaths among people in this same age group. However, a non-statistically significant decrease was noted for the other age groups.

The literature includes several studies investigating evidence of increases in morbidity during forest fire events compared with morbidity noted during control periods. Some studies examined hospitalization for respiratory or cardiovascular problems or emergency room visits, whereas others examined symptoms associated with wildland fires or with medication use.

From a questionnaire, Mott *et al.* (2002) noted an increase in medical examinations for respiratory problems during forest fire events on a native reserve in California in 1999 compared with the number of examinations recorded in 1998, the fire-free control year. Moore *et al.* (2006) also observed increases in medical consultations for respiratory problems during forest fire events in 2003 in a British Columbia city on the periphery of fire sites (daily PM<sub>2.5</sub> maximum: 200 µg/m<sup>3</sup>) compared with the examinations noted for the control years. However, this was not the case in a more remote city, where particulate levels were lower (daily PM<sub>2.5</sub> maximum: 140 µg/m<sup>3</sup>). No increases in medical consultations for cardiovascular or mental health problems were noted in this study.

In keeping with the Moore *et al.*, study (2006), which suggests that particles from wildland fires cause mainly respiratory effects, Mott *et al.* (2005) noted increases in hospital admissions for respiratory problems, but not for cardiovascular problems, in Kuching, Malaysia, during a forest fire period, compared with expected admissions during a fire-free period. Chen *et al.* (2006) also reported increases in hospitalizations for respiratory problems in Australia during brush fires. Other authors report increases in emergency room visits (Viswanathan *et al.*, 2006, Johnston *et al.*, 2002) and even increases in ambulance calls for respiratory problems (Vilke, Smith *et al.*, 2006) during fire events. In some studies, such as Rappold *et al.* (2011) conducted in North Carolina, cities exposed to peat bog fire smoke (daily hourly PM<sub>2.5</sub> maximum > 200 µg/m<sup>3</sup>) saw increases in the use of medical services (emergency room visits) that were more pronounced for respiratory problems than for cardiovascular problems during fire events, compared with the use of medical services in a fire-free period (Poisson models with control for time trends).

In addition to increased use of medical services (hospitalizations and emergency room visits), increases in symptoms were noted in populations exposed to wildland fire smoke. Kunzli *et al.* (2006) studied 16 California communities and observed increases in symptoms such as eye irritation, nasal congestion and bronchitis, as well as increases in medication use and medical consultations (assessed through questionnaires for children and adolescents) with an increase in the duration of forest fire smoke exposure and in PM<sub>10</sub> levels over five days. In asthmatic individuals, Johnston *et al.* (2006) report increases in asthma symptoms and use of asthma medication with increases in daily PM<sub>2.5</sub> and PM<sub>10</sub> levels from wildland fires in Australia. However, this study did not report increases in asthma attacks or use of medical services. Other studies also reported increases in symptoms in populations exposed to wildland fire smoke (Kolbe *et al.*, 2009; Sutherland *et al.*, 2005; Golshan *et al.*, 2002).

The authors of a few other recent studies conducted in 2011 compared medication use. Camano-Isorna *et al.* (2011) noted that after forest fires, there was an increase in medication use for treating chronic obstructive diseases in municipalities in a Spanish province highly exposed to fires (more than 10 fires) compared with use of the same medications in municipalities with low fire exposure (fewer than 4 fires). Vora *et al.* (2011) also observed an increase in medication use in some asthmatics during forest fire events.

### **Summary of epidemiological study results**

Based on the studies published to date, wildland fires and increases in particles from vegetation combustion were associated with increased use of medical services (emergency room visits, hospitalizations, medical consultations), particularly for respiratory problems. Respiratory symptoms and mucous membrane irritation also seemed to increase in populations exposed to particles from wildland fires. Few studies suggest mortality increases.

It is currently impossible to conclude that there is a difference between the respiratory impacts of particles from combustible vegetation fires and the respiratory impacts of particles in urban areas. However, contrary to studies conducted in urban areas, most of the studies investigating the impacts of particles from wildland fires did not report associations with use of medical services for cardiovascular problems.

Most of the studies presented here were conducted on the general population, but in some, analyses by age group or for specific age groups (e.g.: young children, seniors) were completed (e.g.: Analitis *et al.*, 2011; Rappold 2010; Morgan *et al.*, 2010, Delfino *et al.*, 2009; Kunzli *et al.*, 2006; Mott *et al.*, 2005), as were analyses for people who are vulnerable because of their health (e.g.: Sutherland 2005). The evidence is still limited and it is difficult to conclude that people with respiratory problems (asthma, emphysema, chronic bronchitis, chronic obstructive pulmonary disease, etc.) and seniors are more vulnerable to the impacts of particles specifically from wildland fires.

### **Protective measures and interventions**

Recommendations have been enacted by various agencies such as the EPA (2008) to protect populations against the impacts of forest fire smoke. These recommendations, which apply specifically to people who live near combustion sources, include spending less time outdoors and limiting intense physical activity. They target people who are sensitive to smoke and those who are affected by it (e.g.: eye irritation, coughing, etc.) despite being in good health. Forest fire smoke exposure could also exacerbate the conditions of potentially vulnerable people with existing health problems, leading in serious cases to hospitalization or death. Therefore, specific recommendations for forest fire events exist for various sectors, such as health care institutions, particularly in areas adjacent to the fire sites. For remote urban areas, protective measures should be similar to those taken for specific events<sup>1</sup> (HCSP 2012).

However, there is currently little data on which to base recommendations for effective measures to reduce either the general population's exposure during particle events or the effects of said exposure. Kunzli *et al.* (2006) noted the benefits of wearing a mask and

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<sup>1</sup> When high PM concentrations exceeding limit/target values are observed because of the conjunction between human and natural activities (including weather-related activities) conducive to particle formation and accumulation.

limiting time spent outdoors or using air conditioning during fire events. The health effects reported in questionnaires were less pronounced when individuals stated that they had used these measures.

Another study investigated the effectiveness of various intervention strategies for reducing the population's exposure and possibly morbidity during forest fire events (Mott *et al.*, 2002). The authors retrospectively assessed the effectiveness of several public health measures aimed at reducing symptoms: free distribution of masks with and without filters; vouchers for free accommodations at hotels in areas far away from the smoke to make population evacuation easier; and distribution of HEPA filter air purifiers<sup>2</sup> that are very effective for residential use. The authors reported conclusive results regarding use of purifier filters, but similar to Naeher *et al.* (2007) and contrary to Kunzli *et al.* (2006), the results for mask use were mixed.

Research is required for this type of study, not only to improve understanding of the health effects of wildland fire smoke, but also to determine which measures are effective, particularly for vulnerable populations adjacent to fire sites.

Studies conducted in other contexts can also guide public health interventions. According to some studies, unless indoor particle sources (e.g.: cigarette smoke) were present, indoor particle levels would be lower than their outdoor levels. Therefore, when there are wildland fires, staying indoors and closing the windows or limiting physical activities outdoors can be recommended. However, the recommendations must be qualified to avoid increasing exposure to other health risks, such as extreme heat that can accumulate inside homes or pollutants emitted from indoor sources. In addition, studies conducted in areas where wood heating is commonly used reported that HEPA filters were effective for reducing particle levels (Henderson, Milford *et al.*, 2005).

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<sup>2</sup> High Efficiency Particulate Air Filter.

**Table 1 Summary of studies on the health impacts of wildland fires and the association between particles from these fires and health events, 2001–2012<sup>1,2,3,4</sup>**

STUDY	COUNTRY	EXPOSURE	HEALTH EFFECT, POPULATION	RESULTS
<b>Associations between particle levels and health events, reported by <math>\mu\text{g}/\text{m}^3</math> of particles</b>				
Yadav <i>et al.</i> (2003)	Borneo (Southeast Asia)	Forest fires, average daily hourly PM10 levels > 50 $\mu\text{g}/\text{m}^3$ (worst values around 200 $\mu\text{g}/\text{m}^3$ ) with daily maxima reaching 1 800 $\mu\text{g}/\text{m}^3$	Cases of respiratory diseases (asthma, bronchitis, acute respiratory infections) reported by hospitals (all ages)	- Correlation between PM10 levels and respiratory diseases during fire events; absence of correlation during control period
Cançado <i>et al.</i> (2006)	Brazil	Sugar cane burning, average daily PM10 levels: 88 $\mu\text{g}/\text{m}^3$	Hospital admissions for respiratory diseases; age groups	- Association (+)
Johnston <i>et al.</i> (2006)	Australia	Brush fires, average daily PM10 levels: 20 $\mu\text{g}/\text{m}^3$	Asthmatics (251); symptoms, medication use, asthma attacks and use of medical services surveyed by questionnaire; adults and children	- Associations (+) with asthma symptoms and medication use - No association with asthma attacks or use of medical services
Arbex <i>et al.</i> (2007)	Brazil	Sugar cane burning, average daily TSP levels: 57 $\mu\text{g}/\text{m}^3$	Hospitalizations for asthma; all ages	- Association (+)
Johnston <i>et al.</i> (2007)	Australia	Brush fires, median daily PM10 levels: 19 $\mu\text{g}/\text{m}^3$	Hospitalizations for cardiovascular and respiratory problems; Aboriginals and non-Aboriginals of all ages	- Association (+) with hospitalizations for chronic obstructive pulmonary diseases (COPD) and asthma - Association (–), sometimes non-statistically significant, with infections and visits for cardiovascular problems - More pronounced effects for the Aboriginal subgroup
Hanigan <i>et al.</i> (2008)	Australia	Brush fires, average daily PM10 levels: 21 $\mu\text{g}/\text{m}^3$	Hospitalizations for cardiovascular and respiratory problems; Aboriginals and non-Aboriginals of all ages	- Association (+) with hospitalizations for respiratory problems (asthma and COPD) - Association (–), sometimes non-statistically significant, with infections and cardiovascular problems - More pronounced effects for Aboriginals
Hänninen <i>et al.</i> (2009)	Finland	Forest fires, PM2.5, worst hourly concentration: > 180 $\mu\text{g}/\text{m}^3$	Deaths from all causes (all ages)	- Non-statistically significant association (+)

**Table 1 Summary of studies on the health impacts of wildland fires and the association between particles from these fires and health events, 2001–2012<sup>1,2,3,4</sup> (continued)**

STUDY	COUNTRY	EXPOSURE	HEALTH EFFECT, POPULATION	RESULTS
<b>Associations between particle levels and health events, reported by <math>\mu\text{g}/\text{m}^3</math> of particles (continued)</b>				
Delfino <i>et al.</i> (2009)	United States	Forest fires, PM2.5, worst day > 240 $\mu\text{g}/\text{m}^3$	Hospitalizations for cardiovascular and respiratory problems; age groups	<ul style="list-style-type: none"> <li>- Associations (+), especially for respiratory problems</li> <li>- Indications that the effect is not solely associated with PM2.5</li> </ul>
Tham <i>et al.</i> (2009)	Australia	Brush fires, PM10, worst day > 288 $\mu\text{g}/\text{m}^3$	Medical consultations, hospitalizations for respiratory problems, and emergency room visits; age groups	<ul style="list-style-type: none"> <li>- Associations (+) (statistically significant only for emergency room visits for respiratory problems)</li> </ul>
Arbex <i>et al.</i> (2010)	Brazil	Sugar cane burning, average daily TSP levels: 57 $\mu\text{g}/\text{m}^3$	Hospitalizations for hypertension; all ages	<ul style="list-style-type: none"> <li>- Association (+)</li> </ul>
Morgan <i>et al.</i> (2010)	Australia	Brush fires, daily PM10 levels > 42 $\mu\text{g}/\text{m}^3$	Deaths from and hospitalizations for cardiovascular and respiratory problems; all ages	<ul style="list-style-type: none"> <li>- Associations (+) with hospitalizations for respiratory problems</li> <li>- No statistically significant association with mortality or with hospitalizations for cardiovascular problems, sometimes even (-)</li> </ul>
Henderson <i>et al.</i> (2011)	Canada	Forest fires, average daily PM10 levels: 29 $\mu\text{g}/\text{m}^3$	Medical consultations and hospitalizations for cardiovascular and respiratory problems; age groups	<ul style="list-style-type: none"> <li>- Associations (+) with medical services for respiratory problems</li> <li>- No association with cardiovascular problems except for people between the ages of 40 and 50 and &gt; 80</li> </ul>
<b>Comparison of health events during one or more occurrences with events during normal periods or in control communities – associative studies of individuals, along with exposure categories, are included here</b>				
Mott <i>et al.</i> (2002)	United States	Forest fires, PM10, worst day > 500 $\mu\text{g}/\text{m}^3$	Residents of a native reserve, many of whom have diseases; medical consultations for respiratory problems reported in a questionnaire; age groups	<ul style="list-style-type: none"> <li>- Increases</li> </ul>

**Table 1 Summary of studies on the health impacts of wildland fires and the association between particles from these fires and health events, 2001–2012<sup>1,2,3,4</sup> (continued)**

STUDY	COUNTRY	EXPOSURE	HEALTH EFFECTS, POPULATION	RESULTS
<b>Comparison of health events during one or more occurrences with events during normal periods or in control communities – associative studies of individuals, along with exposure categories, are included here (continued)</b>				
Sastry (2002)	Malaysia	Forest fires, PM10, worst day > 400 $\mu\text{g}/\text{m}^3$	Deaths from all causes, including cardiovascular and respiratory problems; age groups	<ul style="list-style-type: none"> <li>- Increases (all causes) for cardiovascular and respiratory problems (non-statistically significant increases for respiratory problems) in people between the ages of 65 and 74</li> <li>- Statistically non- significant decreases in the other age groups</li> </ul>
Golshan <i>et al.</i> (2002)	Iran	Rice field burning, average daily breathable levels during events: 2.3 $\text{mg}/\text{m}^3$	Symptoms and lung functions; residents of a village (n = 994)	<ul style="list-style-type: none"> <li>- Decrease in lung functions</li> <li>- Increase in symptoms</li> </ul>
Sutherland <i>et al.</i> (2005)	United States	Forest fires, PM2.5, worst day: 63 $\mu\text{g}/\text{m}^3$	Individuals with COPD (n = 21); symptoms; average age: 69	<ul style="list-style-type: none"> <li>- Increase in symptoms</li> </ul>
Mott <i>et al.</i> (2005)	Malaysia	Forest fires	Hospitalizations for cardiovascular and respiratory problems; age groups	<ul style="list-style-type: none"> <li>- Increases in respiratory problems, especially for the 40–64 age group</li> <li>- No significant differences for cardiovascular problems</li> </ul>
Vedal <i>et al.</i> (2006)	United States	Forest fires, PM10, worst day: 91 $\mu\text{g}/\text{m}^3$	Deaths from cardiovascular and respiratory problems; all ages	<ul style="list-style-type: none"> <li>- Increases in exposed and non-exposed cities</li> </ul>
Chen <i>et al.</i> (2006)	Australia	Brush fires, worst day > 50 $\mu\text{g}/\text{m}^3$	Hospitalizations for respiratory problems; (all ages)	<ul style="list-style-type: none"> <li>- Increase</li> </ul>
Moore <i>et al.</i> (2006)	Canada	Forest fires, PM2.5, worst day: 200 $\mu\text{g}/\text{m}^3$ in the city near the fire site	Medical consultations for cardiovascular/respiratory and mental health problems; all ages	<ul style="list-style-type: none"> <li>- Increases in consultations for respiratory problems only in the city located in the area of the fire sites</li> <li>- No increases in consultations for cardiovascular or mental health problems</li> </ul>
Kunzli <i>et al.</i> (2006)	United States	Forest fires, five-day average PM10 levels for the worst region: 252 $\mu\text{g}/\text{m}^3$	Symptoms, medication use and medical consultations surveyed by a questionnaire; children (n = 873) and adolescents (n = 5551)	<ul style="list-style-type: none"> <li>- Increases</li> </ul>

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STUDY	COUNTRY	EXPOSURE	HEALTH EFFECT, POPULATION	RESULTS
<b>Comparison of health events during one or more occurrences with events during normal periods or in control communities – associative studies of individuals, along with exposure categories, are included here (continued)</b>				
Viswanathan <i>et al.</i> (2006)	United States	Brush fires, worst daily PM10 levels: 294 µg/m <sup>3</sup>	Emergency room visits for asthma, respiratory problems, eye irritation and smoke inhalation; all ages	- Increase in examinations for respiratory problems (asthma, other respiratory problems), but not for chest pain; total examinations did not increase
Vilke <i>et al.</i> (2006)	United States	Brush fires	Ambulance calls, all ages	- Increases in calls, especially for respiratory problems (most people transported to hospital)
Kolbe <i>et al.</i> (2009)	Australia	Forest fires, PM10, worst day: 415 µg/m <sup>3</sup>	Symptoms surveyed (n = 389); all ages	- Increase in symptoms.
Johnston <i>et al.</i> (2011)	Australia	Brush fires, daily PM10 levels > 47 µg/m <sup>3</sup>	Deaths from all causes, including cardiovascular and respiratory problems; all ages	- Statistically insignificant increases, except for all causes
Rappold <i>et al.</i> (2011)	United States	Peat bog fires, maximum daily hourly PM2.5 levels > 200 µg/m <sup>3</sup> .	Emergency room visits for cardiovascular and respiratory problems	- More pronounced increases for emergency room visits for respiratory problems than for cardiovascular problems
Analitis <i>et al.</i> (2011)	Greece	Forest fires	Deaths from all causes, including cardiovascular and respiratory problems; age groups	- Increases (especially for respiratory problems) not affected by the addition of black smoke levels in statistical models
Caamano-Isorna <i>et al.</i> (2011)	Spain <sup>o</sup>	Forest fires	Retirees; COPD medication use	- Increase
Vora <i>et al.</i> (2011)	United States	Forest fires, PM2.5, worst day: 72 µg/m <sup>3</sup>	Asthmatics (small n of 8); lung functions and medication use	- No decrease in lung function - Increase in medication use

<sup>1</sup> PM10 levels are reported when available because they are the most used. "n"s (number of people in the study) are not presented for the population studies conducted with databases listing deaths or with medico-administrative databases.

<sup>2</sup> Two studies (Jalaludin *et al.*, 2004 and Schranz *et al.*, 2010) were not included because only summaries were available.

<sup>3</sup> A study by Kunii *et al.* (2002) was not included because the authors do not proceed by comparison, but rather only by transversal investigation during an event.

<sup>4</sup> A study by Ovadnevaite *et al.* (2006) conducted in Lithuania reports increases in medical examinations for respiratory problems during a fire event. However, it was not included because the methods are not sufficiently described in the article. The Lee *et al.* (2009) study was not included for the same reasons.

## CONCLUSION

Forest fires inherently present a real threat on various levels, whether ecological or economic. In the context of climate change where this type of event may increase, it is therefore reasonable to investigate the related health impacts. It is essential to differentiate the exposure of neighbouring populations and firefighters from that of populations living in distant areas. When forest fire smoke reaches those distant areas, the concerns centre on the health impacts of fine particles.

Most epidemiological studies suggest that particles from wildland fires mainly cause short-term respiratory impacts and few cardiovascular impacts. The population, including potentially vulnerable people such as those with respiratory problems, should remain vigilant during forest fire events and take steps to minimize exposure and thereby avoid an exacerbation of symptoms, possible hospitalization, and even death.

According to current knowledge, particles from forest fire smoke can be considered at least as hazardous to short-term respiratory health as particles from urban sources. It therefore seems reasonable to treat forest fire smoke as a specific particle pollution event (like typical urban pollution peaks) and comply with existing recommended protective measures (HCSP 2012). In addition, for the time being, population impacts (attributable risks) of particles from wildland fires can be quantified based on the risks noted in studies conducted in urban areas.

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