Special Projects

Studies and Research Projects

REPORT **R-775**

Impacts of Climate Change on Occupational Health and Safety

Ariane Adam-Poupart
France Labrèche
Audrey Smargiassi
Patrice Duguay
Marc-Antoine Busque
Charles Gagné
Joseph Zayed

Established in Québec since 1980, the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) is a scientific research organization known for the quality of its work and the expertise of its personnel.

OUR RESEARCH
is *working* for you !

Mission

To contribute, through research, to the prevention of industrial accidents and occupational diseases, and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety prevention network.

Funded by the Commission de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more

Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to Prévention au travail, the free magazine published jointly by the IRSST and the CSST.
Subscription: www.csst.qc.ca/AbonnementPAT

Legal Deposit
Bibliothèque et Archives nationales du Québec
2013
ISBN: 978-2-89631-668-7 (PDF)
ISSN: 0820-8395

IRSST – Communications and Knowledge Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
Fax: 514 288-7636
publications@irsst.qc.ca
www.irsst.qc.ca

Special Projects

Studies and Research Projects

REPORT **R-775**

Impacts of Climate Change on Occupational Health and Safety

Disclaimer

Ariane Adam-Poupart[1], France Labrèche[2], Audrey Smargiassi[1], Patrice Duguay[3], Marc-Antoine Busque[3], Charles Gagné[4], Joseph Zayed[1,3]

[1]Université de Montréal

[2]Chemical and Biological Hazards Prevention, IRSST

[3]Scientific Division, IRSST

[4]Communications and Knowledge Transfer Division, IRSST

Clic Research
www.irsst.qc.ca

This publication is available free of charge on the Web site.

This study was financed by the IRSST. The conclusions and recommendations are those of the authors.
This publication has been translated; only the original version (R-733) is authoritative.

ABSTRACT

The effects of climate change (CC) are often discussed in terms of its impacts on the environment and the general population. To date, the scientific community has focused very little on its repercussions on occupational health and safety (OHS), yet workers can be affected both directly and indirectly by CC, notably by the heat stress to which they may be exposed and by changes in the ecosystems that form the basis of their economic activities. The general objective of this study was to explore research topics relating to the negative impact of climate change on occupational health and safety. More specifically, the goals were to (1) provide an overview of (conceptual framework for) the links between CC and its potentially adverse effects on OHS in Québec, (2) plan and implement a working and consultation procedure promoting national and international dialogue and reflection, and (3) identify the priority research topics pertinent to Québec, in terms of knowledge needs.

First, a review of the literature published between 2005 and 2010 was performed to identify the main links between CC and OHS in Québec. This knowledge review highlighted five categories of hazards that could potentially have direct or indirect impacts on OHS in Québec: heat waves, air pollutants, ultraviolet radiation, extreme weather events, and communicable vector-borne and zoonotic diseases. Another five conditions that could lead to changes in the work environment and have negative impacts on OHS in Québec were also identified: changes in agricultural and animal husbandry methods, changes in the fishing industry, disturbances of the forest ecosystem, degradation of the built environment, and the emergence of new “green” industries.

A consultation process was then initiated by forming a working group made up of national and international experts and Québec stakeholders from the following economic activity sectors: agriculture, construction, forestry, mining, municipal services, transportation, fishing, wind power research, and public health. At two workshops held in Montréal, this working group first verified the credibility and completeness of the information retrieved from the literature review and then helped identify research topics.

Lastly, the priority research topics were determined by means of two rounds of consultation with members of both the working group and the research team, using the Delphi method. This iterative consultation procedure resulted in a consensus on 12 priority research topics pertinent to Québec. These topics were in turn categorized according to three major research orientations: the acquisition of knowledge on hazards and target populations, epidemiological surveillance, and the development of adaptation measures.

TABLE OF CONTENTS

FIGURES

INITIALISMS, ACRONYMS, AND ABBREVIATIONS

CC:	Climate change
CDC:	Centers for Disease Control and Prevention (United States)
CO_2:	Carbon dioxide
EC:	Environment Canada
HC:	Health Canada
INSPQ:	Institut national de santé publique du Québec
IPCC:	Intergovernmental Panel on Climate Change
IRSST:	Institut de recherche Robert-Sauvé en santé et en sécurité du travail
NHS:	National Health Service (United Kingdom)
NRC:	Natural Resources Canada
OHS:	Occupational health and safety
UNEP:	United Nations Environment Programme
USEPA:	US Environmental Protection Agency
WHO:	World Health Organization

1. INTRODUCTION

A consensus on the rapid pace of climate change has existed among scientists for over 20 years now. According to the conclusions presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), global warming—that is, "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period"—is unequivocal [1, 2]. The IPCC projects that the average increases in surface temperatures and the concomitant increased concentrations of atmospheric carbon dioxide (CO_2) will result in major alterations in the structure of ecosystems and in ecological interactions, to the detriment of biodiversity and ecosystem-related goods and services [1]. Major environmental variations are projected: (1) temperature, precipitation, humidity, and wind variability, (2) alterations in the intensities and geographic distribution of extreme weather events, (3) significant rises in water levels in coastal regions, (4) alterations in vegetation and wildlife distribution, (5) increased atmospheric concentrations of pollutants, and (6) a deterioration in natural habitats and the built environment [1, 3, 4, 5].

The impacts of climate change (CC) on human health are numerous and varied. Some factors, such as heat waves, will have a direct impact on human health. Others, such as changes in the distribution of pathogens that cause infectious diseases, will affect human health indirectly [2, 6]. Still others will disrupt the ecosystems that sustain human life and will affect infrastructures (e.g. electrical and telecommunication lines), as well as land, sea, and air transport systems [4, 6, 7].

Generally speaking, the impacts of CC on public health, the environment, and human activities are relatively well documented, which is not the case for its impacts on the work world. Yet climate change will likely have both positive and negative consequences for the work world that will be modulated by any given country's sociopolitical and economic organization [8]. In a northern countries with a temperate climate such as that in Québec, the new climate conditions could prove beneficial for hydroelectric and forestry productivity. Certain agricultural crops, such as corn or soybeans, and free-range husbandry practices could benefit from global warming [6]. However, CC could also have adverse effects on the work world, notably on occupational health and safety (OHS). For example, workers may be particularly affected, either directly or indirectly, by the exacerbation of the heat stresses to which they may be exposed or by changes in the ecosystems that form the basis of economic activities [4].

Although very few studies have specifically explored the negative impacts of CC on OHS, a review of such literature published between 1998 and 2008 was performed by Schulte and Chun in 2009 [9]. The main climate-related global hazards they identified were: (1) increased ambient temperature, (2) air pollution, (3) exposure to ultraviolet radiation, (4) extreme weather events, (5) communicable vector-borne diseases and expanded vector habitats, (6) industrial transitions and emerging industries, and (7) changes in the built environment. The conceptual framework developed by these authors visually depicts the relationships among the various risk factors and OHS issues. Figure 1 shows an adapted version of this conceptual framework.

Based on their analysis, Schulte and Chun concluded that while CC may increase the prevalence, distribution, and severity of known occupational hazards, there is no evidence that it will lead to unique or previously unknown hazards. However, they also found that potential interactions among known risks and new working conditions could lead to new hazards and risks [9]. The authors made two recommendations: (1) that the relative magnitude and frequency of the environmental hazards associated with climate change should be evaluated on a regional basis, and (2) that a research and prevention program should be developed on the basis of a prioritization scheme for certain issues.

In Québec to date, no agency or institution has clearly initiated a reflection process on the OHS issues related to CC. This area is still in its embryonic phases. It was against this backdrop that this study was carried out by a research group comprising members with complementary areas of expertise (Appendix A).

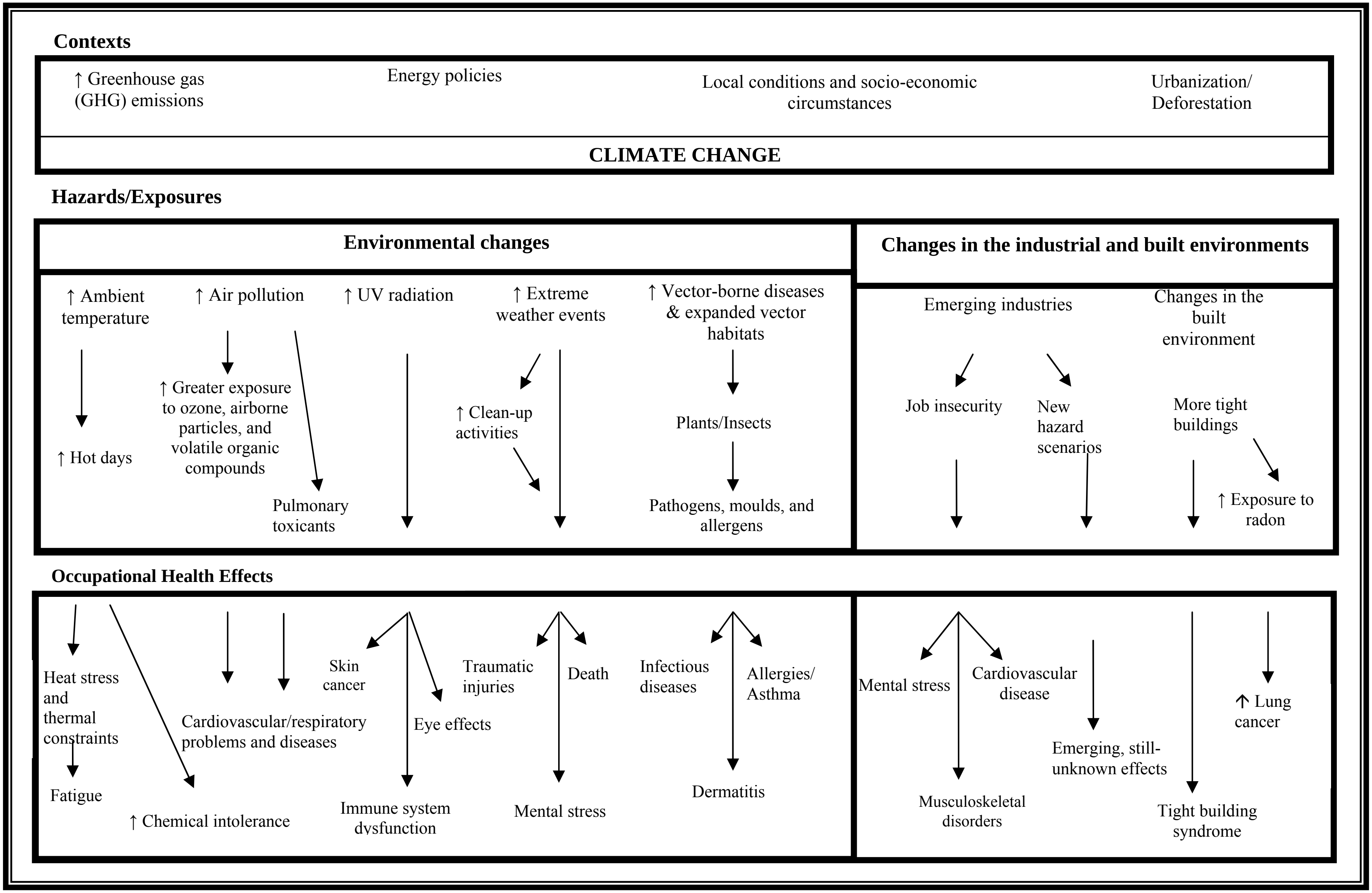

Figure 1 – Conceptual framework of the relationship between climate change and occupational safety and health (adapted from Schulte and Chun, 2009).

2. OBJECTIVES

Despite the fact that climate change may have some beneficial effects on the work world and possibly on OHS, this study focused on its adverse effects. The general objective was therefore to explore research topics relating to the potentially negative impacts of CC on OHS in Québec. More specifically, the goals were to:

1) provide an overview of (conceptual framework for) the links between CC and its potentially adverse effects on OHS in Québec;

2) plan and implement a working and consultation procedure promoting national and international dialogue and reflection;

3) identify the priority research topics pertinent to Québec, in terms of knowledge needs.

3. METHODOLOGY

To achieve all the objectives, a literature review was conducted first in order to gain an overview of the links between CC and OHS in the Québec context. A working and consultation procedure promoting dialogue and reflection was planned and implemented by forming a group of national and international experts and Québec industry stakeholders. This working group began by verifying the completeness of the information identified in the literature and then identified pertinent research topics.

3.1 Literature review

The potential links between CC and its adverse effects on OHS in the Québec context were identified by means of a literature review involving peer-reviewed articles and literature reviews published in scientific journals, as well as information obtained from government documents and websites. The review focused on the CC hazards evidenced in the climatic and socio-economic realities faced by industrialized countries with a temperate climate.

3.1.1 Peer-reviewed literature

The bibliographic search was performed on Embase, Pubmed, Medline, Web of Science, Toxline, and Chemical Abstracts, using various combinations of the following key words: climate, climate change, global warming and work* or occupation*[1] It essentially covered the period from 2005 to 2010. Relevant articles published prior to this period were mainly identified by examining references cited (snowballing) in Schulte and Chun [9], Jay and Kenny [28], Desjarlais *et al.* [6], and the IPCC documents [13].

Articles were first selected on the basis of their title's pertinence and then manually sorted by applying the following criteria:(1) All the articles retained had to relate directly to occupational health and safety and to mention CC. Exceptionally, a few articles concerning the general population were also retained, particularly when they dealt with subjects on which worker information was lacking and when the general population data could be inferred to workers. (2) Articles reporting hazards, illnesses, zoonotic diseases, and other health effects not found in Québec were not retained. (3) Articles on extreme cold exposure were also excluded because climate projections for Québec suggest an increase rather than decrease in winter temperatures [6]. (4) Lastly, articles written in languages other than French and English were excluded.

[1] The asterisk beside the words *work* and *occupation* indicates that the search was conducted on all terms containing some variant of the words *work* (e.g. work, worker, working) or *occupation* (e.g. occupation, occupational).

3.1.2 Other data sources

Other data sources were also used for the knowledge synthesis. Numerous government and institutional websites were visited, and documents providing pertinent information on the link between CC and OHS were retained. These sites included those of the US Environmental Protection Agency (USEPA), World Health Organization (WHO), National Health Service (NHS), Centers for Disease Control and Prevention (CDC), OURANOS (Québec's Consortium on Regional Climatology and Adaptation to Climate Change), Intergovernmental Panel on Climate Change (IPCC), Health Canada (HC), Environment Canada (EC), Natural Resources Canada (NRC), United Nations Environment Programme (UNEP), National Institute for Occupational Safety and Health (NIOSH), and United States Army.

3.1.3 Data synthesis strategy

The hazards/exposures associated with CC, the effects on OHS, and the types of industries potentially affected by CC were identified in the articles and documents retained. They were then divided into major theme categories inspired by those defined by Schulte and Chun [2009].

A total of 209 scientific articles and literature reviews, as well as relevant information from around a dozen websites, were retained. A schematic diagram showing the methodology used and number of articles excluded by applying the various criteria is found in Appendix B.

3.2 A working and consultation procedure promoting dialogue and reflection

To verify the completeness of the information identified in the literature review, the research team (Appendix A) presented a summary of this information to a working group at two workshops: to the panel of national and international experts at the first workshop, and to stakeholders from Québec's economic activity sectors at the second workshop.

3.2.1 Formation of the panel of experts

The members of the panel of experts were selected to ensure a broad range of expertise on the hazards/impacts of CC on OHS. Two experts on the OHS effects of ambient temperature and heat stress were therefore recruited, along with two other experts on the health and environmental impacts of CC and on adaptation measures, one expert in emergency medicine, another in the field of zoonotic diseases, and a last expert on the health effects of UV radiation. A list of the experts recruited and their professional affiliations is provided in Appendix C.

3.2.2 Formation of the group of stakeholders from the economic activity sectors

The economic activity sectors from which stakeholders were invited to attend the second workshop were selected to represent the main sectors that would potentially be affected by CC in Québec. Stakeholders from the agriculture, construction, forestry, mining, municipal services, transportation, fishing, wind power research, and public health sectors thus participated in the working group.

3.3 dentification and prioritization of research topics

3.3.1 Identification of research topics

At the two workshops and following a presentation of the literature review on the impacts of CC on OHS to the working group, the members first identified the knowledge gaps. They then proposed research topics that could be pursued in Québec to fill in these gaps. A list of thirty research topics emerged from the workshop discussions (Appendix D).

3.3.2 Prioritization of research topics

A modified version of the Delphi method was used to identify the main research topics. The Delphi method involves holding a series of consultations aimed at achieving a consensus on priority issues by a statement priority-ranking process. The consultation process usually ends when a consensus is reached or agreement on priorities is sufficiently advanced [10].

The first list of research-topic statements was emailed to the members of the working group (n=19) and the research team (n=7). The respondents were asked to add to and comment on the list of statements.

The responses obtained were then examined and a revised list of statements was produced and returned to the same individuals (n=26). During the second round of consultation, the participants had to select the ten most important research topics and rank them in order of priority from 1 to 10; they were again asked to submit comments. Lastly, the assigned rankings were compiled and the priority research topics categorized.

4. RESULTS

4.1 Knowledge synthesis

This section provides an overview of the current knowledge and presents the main issues pertaining to the negative impacts of CC on OHS in Québec, as identified in the literature and supplemented by the working group (of experts and sectoral stakeholders). Figure 2 presents all this information organized within a conceptual framework inspired by that of Schulte and Chun [2009]. Three levels of consequences emerged from our analysis: consequences for individuals, consequences for natural resources, and consequences for the socio-economic context. Five categories of exposures and hazards that could impact directly or indirectly on OHS in Québec were identified: heat waves, air pollutants, ultraviolet (UV) radiation, extreme weather events, and communicable vector-borne and zoonotic diseases. In addition, five other conditions were identified that could lead to changes in the work environment and have negative impacts on OHS: changes in agricultural and animal husbandry methods, changes in the fishing industry, disturbances of the forest ecosystem, degradation of the built environment, and the emergence of new “green” industries.

4.1.1 Consequences for individuals

The first main theme identified in the literature concerns the impacts of climate change that will have direct or indirect consequences for individuals. These concern heat waves, air pollutants, UV radiation, extreme weather events, and communicable vector-borne and zoonotic diseases [1].

Heat waves

Climate projections suggest that the extreme heat episodes and heat waves being experienced by many North American cities will increase in frequency and severity in the coming years [2, 6]. This has been observed mainly in Montréal and Québec City, where summer temperatures and the daily humidex[2] have been on the rise for the past four decades, a phenomenon compounded by the effect of heat islands, which raise ambient air temperatures locally by 0.5 °C to 5.6 °C. However, temperature increases throughout Québec are projected to be more pronounced during the winter [6].

The **potential effects** of heat exposure on OHS are both direct and indirect. Generally speaking, exposure to high ambient temperatures causes an increase in body temperature, which translates into cutaneous vascular dilation, sweating, and increased heart rate. At a body temperature of 38-39 °C, the risks of heat exhaustion are high and symptoms associated with heat stress appear.

[2] A heat index used in Canada to describe the combined effect of heat and humidity.

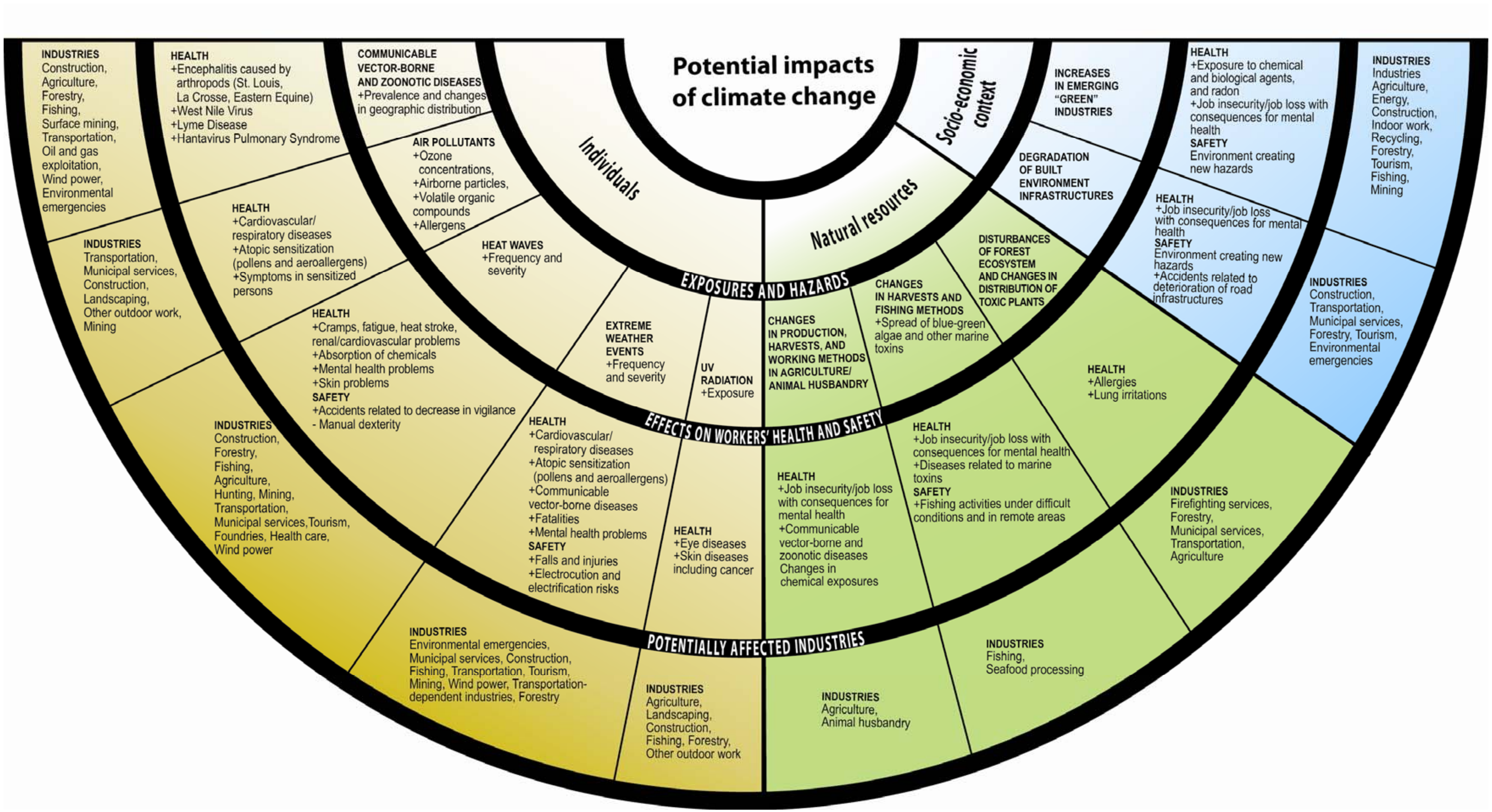

Figure 2 – Conceptual framework of the potential impacts of climate change on occupational health and safety in Québec

Heat stroke (that is, when the central nervous system's thermoregulation system fails) generally occurs when the body temperature reaches around 40–41 °C [11, 12, 13]. When there is high relative air humidity, sweat evaporation and, consequently, the heat dissipation rate may also be compromised, thus accelerating the rising body temperature phenomenon. Carrying out prolonged physical activity in a hot, humid environment increases the risks of heat exhaustion and heat stroke [14, 15]. Recommendations regarding OHS in hot environments therefore generally include measurements of the humidity level [16]. In addition to these symptoms, excessive heat exposure can cause heart and kidney problems [17]. Exposure to a hot environment also changes physiological parameters such as pulmonary ventilation, vasodilation, sweating, and blood flow, thereby causing increased absorption of xenobiotics through pulmonary or cutaneous routes [18, 19].

The **indirect effects** of heat exposure translate into an increased risk of bodily harm and injury, caused by fatigue and reduced vigilance [for a review, see 20]. The accident incidence rate is minimal when the work activity is performed at temperatures of approximately 17 °C to 23 °C WBGT[3], but increases with lower or higher temperatures [21]. Work performed at a high ambient temperature can change worker skills and capacities when physical tasks are involved; this in turn can have consequences on work capacity, productivity, and safety. A number of factors could explain this phenomenon. For one, psychomotor performance, including manual dexterity, can be altered by heat exposure. The physical discomfort associated with an increase in body temperature can also alter the worker's emotional state (e.g. irritability or anger), leading to negligence regarding safety procedures and reducing vigilance during the performance of dangerous tasks [22]. The dehydration caused by exposure to a hot environment also seems to have effects on cognitive performance, visual motor capacities, short-term memory, and vigilance [for a review, see 23]. Lastly, one particular aspect of northern countries in relation to OHS that was emphasized at the workshops is that warmer winters would reduce outdoor workers' vigilance and adaptation to the cold, which could increase the risk of injury[4].

Several illustrations of the effects of heat on OHS are found in the literature. In Canada, 49 deaths attributable to excessive natural heat were reported between 2000 and 2007 in workers between ages 20 and 64; however, information about the circumstances surrounding the deaths was not available [24]. In France, several deaths caused by hyperthermia in the workplace (including three young people in one day) were identified during the 2003 and 2006 heat waves [25], while in Japan, between 19% and 29% of reported cases of heat stroke occurred among workers [14]. In the United States, 423 deaths were attributed to heat stroke in the workplace between 1992 and 2006 [26]. Nearly one-quarter of these employees worked in the agriculture, forestry, fishing, and hunting **industries**, and the heat-related death rate in agricultural industries was twenty times higher than that for all civilian workers [26].

Several **factors** can intensify the effects of heat exposure on workers. On the individual level, heat tolerance levels seem to diminish in people over 45 years of age because physical activity is

---

[3] WBGT: The Wet Bulb Globe Temperature index is a composite temperature index used to estimate the effects of temperature, humidity, and solar radiation on humans.
[4] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

more physiologically demanding on them. They sweat more readily and their metabolism takes longer to return to normal [27]. In addition, workers with health problems (such as heart disease, hypertension, or blood circulation problems), workers who are overweight, and those on sodium-restricted diets or who take certain medications [12, 13] are more likely to have problems following excessive heat exposure. Lastly, pregnant women, who have a higher metabolic rate, are also more vulnerable [13].

Location, season, and type of activity are other **factors** that can exacerbate the effects of heat exposure. The most exposed workers are essentially those working in industries where the jobs are performed outside and require intense physical activities during the summer months, or those working at high indoor temperatures or who experience increased body heat due to the nature of their tasks [for a review, see 28]. The fact of wearing protective equipment can also aggravate the effect of heat on certain groups of workers [29, 30]. As well, it appears that heat stroke occurs more frequently at the start of the hot season and at lower temperatures when workers are not yet acclimatized: this was reported at the workshops, for Québec construction, agricultural, and forestry workers[5]. Lastly, the existence of an association between high temperatures, carbon monoxide exposure, and decreased performance has been reported among racing car drivers [31]. Higher temperature are also associated with faster water evaporation, which increases skin problems in workers exposed to seawater, especially in the presence of solar radiation; this too was emphasized at the workshops for workers from the fishing sector[5].

Other industries that pose risks of heat stroke include mining, transportation (bus and taxi drivers, road and dam construction or repair workers, and roadside brush cutters), waste materials management, landscaping, postal services, and firefighting services. Industries involving indoor activities with risks of excessive heat exposure are the glass, ceramic, brick, and rubber fabrication industries; foundries; greenhouses; canning and textile industries; and laundries, kitchens, and warehouses [9, 32, 33, 34, 35]. As pointed out at the workshops, workers in the wind power sector may also be exposed to extreme heat (when they have to make emergency repairs to wind turbines during the summer), as may healthcare workers, particularly those in emergency services (ambulance technicians and emergency services personnel), who often have to work under pressure in rooms with no air conditioning while wearing protective clothing[6].

Air pollution

Air pollutants

Climate projections suggest that CC may affect the levels of air pollutants, including ozone, particulate matter, volatile organic compounds (VOCs), and other greenhouse gases. Changes in weather patterns (variations in temperatures, precipitation, and wind patterns) could increase the

[5] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

[6] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

frequency and severity of air pollution episodes, while growing energy demands could increase the emission of certain pollutants or their precursors [2, 5]. In Québec, the increase in temperatures could foster the increase in ambient concentrations of several pollutants (including ground-level ozone) and increase the durations of periods when standards are exceeded. While the relationship between CC and particulate levels is still the focus of many studies [6], climate projections suggest that summer concentrations of particulate matter would remain stable or slightly regress in the upcoming years. On the other hand, the frequency of forest fires in certain regions of Canada and the United States (the northeastern states, Ontario, and Québec) may increase in the decades ahead, which would intensify smoke and particulate concentrations in the ambient air in Québec [2, 6].

The **effects** of exposure to air pollutants consist mainly of the increased incidence and exacerbation of the symptoms of respiratory and cardiovascular diseases [13]. A few studies specifically investigating workers do exist, but they date back twenty years [36]. Ground-level ozone has multiple respiratory effects: coughing, shortness of breath, inflammatory response of the mucous membranes, irritations, reduced respiratory functions, and aggravation of chronic diseases [for a review, see 37]. In addition, ground-level ozone increases the respiratory tract's reactivity to irritating agents, which can lead to an increased number of asthma attacks for asthmatics and to pneumonias [38, 39]. The ground-level ozone outside may also enter buildings, and a combination of this ozone and indoor contaminants (e.g. volatile organic compounds) could impact the indoor air quality and people's health [40]. Regarding the effects of airborne particles on the general population, the literature indicates that they are responsible for exacerbating asthma symptoms and are associated with an increase in hospitalizations and emergency room visits, as well as an increase in respiratory and cardiovascular mortality [41, 42, 43]. Higher pollutant concentrations due to climate change could therefore increase certain health problems in workers.

The health effects associated with air pollutant exposure vary according to a number of **factors**, including environmental concentrations, exposure duration, and respiratory rate [5]. Workers who hold outdoor jobs performed over long periods of time and that require major physical effort have a greater potential of exposure to air pollutants [7] mainly due to the increase in their respiratory flow and the duration of their exposure. The industries most subject to major exposure to air pollutants are the transportation, public services, landscaping, and construction industries [9].

Pollen and other allergens

Climate projections suggest that CC could affect the distribution and concentration of pollens and other aeroallergen (moulds, spores, and mycotoxins) [6]. In fact, the increase in ambient temperatures and higher CO_2 concentrations are expected to promote earlier flowering periods, lengthen pollen seasons, increase the quantities of allergens produced, intensify allergenicity, and change distribution areas [5, 11, 37]. It is further reported that the pollen production season in the northern hemisphere has increased by around 15 days over the past three decades [2, 13]. An increase in concentrations was already documented for the Québec City and Montréal regions between 1994 and 2002. For this same period, the duration of the pollen season lengthened from 40 to 70 days a year [3, 6].

The **effects** of exposure to pollens and other airborne allergens on OHS could translate into an increase in respiratory diseases such as asthma and allergic rhinitis. The components of air pollution interact with the allergens transported by pollen grains and could therefore increase the risks of atopic sensitivity and aggravate symptoms in already-sensitized individuals [for a review, see 5].

No study reporting **factors** that intensify the effects in workers came to light during our literature review. However, as is the case for workers exposed to air pollutants, workers in **industries** where jobs are performed outdoors over long periods of time and require intense physical effort, have a greater potential of exposure to aeroallergens, given the increase in the workers' respiratory flow and the duration of their exposure.

Ultraviolet radiation

In view of the impact of CC on stratospheric ozone, the World Health Organization (WHO) **predicts** an increase in ultraviolet (UV) radiation levels on the earth's surface. This phenomenon appears to be attributable mainly to depletion of the stratospheric ozone layer as a result of the presence of greenhouse gases, changes in atmospheric chemistry that are affected by the warming of the polar regions, and changes in cloud distribution [3, 6, 10]. It is also anticipated that the lengthening of the hot season and the related social behaviours would lead to greater exposure to UV radiation in northern regions such as Québec [2, 6].

Certain **adverse effects** on OHS have been associated with UV radiation, including the development of skin cancers. In fact, ultraviolet rays can penetrate the dermis and alter skin cell structure. Despite the beneficial production of Vitamin D, UV rays can also suppress the immune system and cause acute photokeratitis, conjunctivitis, and cataracts [for a review, see 44, 45].

A number of **factors** can contribute to increasing the incidence and severity of these effects. On the individual level, the people at highest risk of skin cancer are those who have particularly white skin and freckles, and who tend to burn rather than tan in the sun. Taking certain medications (diuretics, some antibiotics, and oral contraceptives) can also sensitize skin to the sun's effects [46]. In a work environment, snow, light-coloured sand, and concrete also reflect UV rays and increase potential exposure. During the summer season, workers are at the greatest risk [47] when the sun's rays are at their highest intensity between 10 a.m. and 4 p.m. Moreover, as mentioned at the workshops, the heat that often accompanies solar radiation induces some workers to remove clothing, thus increasing the skin surface exposed to UV rays[7]. With regard to type of **industries**, farmers and fishermen are among the workers at the highest risk of developing skin cancer since they are exposed to the sun on a daily basis [48, 49]. Very high skin cancer rates have been reported in the United States in farmers and seasonal farm workers [48,49]. Increased exposure to UV radiation also applies to workers in other industries, such as those working in the construction, roadwork, landscaping, and horticulture sectors, as well as lifeguards [47]. Exposure to coal-tar pitch and petroleum products containing polycyclic

[7] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

aromatic hydrocarbons (PAHs), as well as certain chemicals used in the printing industry, can also sensitize skin to the effects of UV radiation [46].

Extreme weather events

According to the IPCC's **predictions**, episodes of heavy and frequent precipitation should greatly increase in many regions around the globe, including regions where a decrease in mean precipitation is anticipated [2]. It is predicted that in Québec as elsewhere, climate change will accentuate the frequency and severity of extreme weather phenomena such as severe thunderstorms, storms, flooding, and droughts [2, 5, 6, 50].

Extreme weather events have multiple **effects** on OHS. Thunderstorms can exacerbate asthma [5] by increasing people's exposure to pollens and other allergens [40]. Summer storms, characterized by heavy rains and flooding, are associated with an increase in heart problems, propagation of vector-borne communicable diseases, risks of hypothermia, and death by drowning [6, 13]. Environmental disasters can also induce sinus congestion, throat irritations, and skin rashes in emergency response workers [51]. Apart from increasing the risks of accidents during emergency interventions, extreme weather events can also have repercussions on workers' mental health, notably in the form of post-traumatic stress disorders [52]. Another indirect consequence associated with rapid changes in weather conditions that was stressed during the workshops is an increased risk of accidents due to an accelerated work pace adopted by construction or other outdoor workers who may try, for example, to finish their tasks before a storm[8].

The main **factors** that change the risk of injuries associated with extreme weather events are the type and location of occupational activity involved and where it is carried out. Response workers who handle environmental emergencies (first aiders, firefighters, police officers, and other workers from the healthcare sector), as well as those in the construction, fishing, transportation, and tourism **industries** are at greater risk of exposure to the hazards associated with sudden, extreme weather events. Farmers are also at greater risk of exposure to contaminants (moulds, chemical products, biological agents) and to fecal matter in the soil during floods, which increase the mobilization and bioavailability of this matter [3, 53]. Moreover, firefighters' exposure to extreme temperatures, smoke, vapours, and toxic gases could increase due to the anticipated increase in forest fire frequency [13]. Lastly, extreme weather events could force workers in remote regions to stay longer than planned on work sites or in mines before being replaced by other workers, thus prolonging their work hours and increasing their accident risk due to lack of rest. This issue was mentioned at the workshops[8].

Communicable vector-borne and zoonotic diseases

The prevalence of vector-borne and zoonotic diseases could increase, according to **predictions** made in connection with CC [2]. Higher temperatures would change incubation rates, transmission seasons, and geographic distributions of vector insects (ticks and mosquitoes) and

[8] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

disease-carrying animals [2, 6]; and the rise in temperatures would facilitate the development or introduction of new pathogens or disease vectors in livestock [for a review, see 54, 55].

The OHS **effects** associated with these phenomena would be an increased incidence of infectious diseases and the appearance of new vector-borne diseases [2]. In Québec, currently there are only a few vector species that carry human diseases, but some are present in the southern part of the province. Rising temperatures will prolong the transmission season and change the distribution areas of the virus-vector arthropods responsible for St. Louis encephalitis, La Crosse encephalitis, Eastern Equine encephalitis, and the West Nile Virus [6], as well as the distribution of the virus host (rodent) responsible for hantavirus pulmonary syndrome (HPS), the first case of which was reported in Québec in 2005 [6]. Lyme's disease is also an emerging zoonotic disease in Canada, and it is expected that this pathology will propagate in several regions of eastern Canada, including Québec, within the next ten or 20 years [6, 56].

The type of occupational activity and work environment are among the main **factors** that contribute to the development and propagation of these diseases. People who work outdoors are those at the greatest risk of exposure to vector-borne and zoonotic diseases [9]. Cases of infection by the West Nile virus were reported in American farmers in 2002 and 2004 [57], and the rate of infection with Lyme's disease among construction workers in New York State was two times higher than that in the general population [57]. The highest-risk **industries** are agriculture, forestry, fishing, construction, mining, road maintenance, and oil and gas extraction [57, 58, 59]. Environmental emergency responders, entomologists, and people who perform necropsies on animals, or who handle possibly infected tissues or fluids are also at risk. Moreover, the propagation of vector-borne diseases could potentially necessitate the increased use of pesticides, in turn increasing worker exposure to these products [55].

4.1.2 Consequences for natural resources

The second major impact theme identified in the literature and by the working group concerned the consequences of climate change for natural resources, specifically those that will directly affect work environments. Climate change can be associated with changes in agricultural/animal husbandry activities, alterations in the fishing industry, and the perturbation of forest ecosystems, with drops in production, revenues, and number of jobs as the main consequences (Figure 2). The main repercussions on workers would be job insecurity and an increase in the problems associated with this phenomenon, such as work dissatisfaction, stress, and physical and mental health problems [for a review, see 60].

The following paragraphs look mainly at the aforementioned themes from the perspective of their socio-economic impacts. **Predictions** suggest that the increase in heat waves and in the number and severity of extreme weather events, as well as increased ozone concentrations, will have negative effects for several industries, including agriculture [for a review, see 61, 62, 63]. However, some studies show that heavy flooding could also have beneficial effects on crops in certain locations by adding nutrients to the soil and improving irrigation. That said, looking only at the adverse effects of climate change, it is possible that levels of employment in the agricultural sector will decline, especially for seasonal jobs, given the anticipated damages to crops and resulting drop in production [4, 7]. In addition, the increased demand for biofuels as a source of renewable energy, which is one of the solutions proposed to counter CC, changes the use made of agricultural land and diverts agricultural production normally geared to food, thus raising an ethical debate and generating major concern about food product availability. Agricultural workers could therefore be required to use more pesticides, resulting in higher exposure.

The effects of CC could also play a role in changing animal husbandry practices. In fact, breeders may resort to more indoor housing of animals in order to limit the effects of heat on them. This could lead to the development of new diseases in animals while increasing the risk of zoonotic diseases [54]. Breeders may also find themselves obliged to use more biocides and veterinary medicines, thereby increasing the cost of stock raising and the potential health risks associated with the use of such chemical products. The long-distance transportation of animals for human consumption could also require more night work on the part of truck drivers as they seek to avoid driving periods of intense heat.

Changes in the fishing industry, notably in fish distribution, as a result of climate variations have already been observed. Generally speaking, predictions suggest that ocean primary production will decline and that the warm-water species will be favoured at the expense of cold-water species [64]. CC could also have unforeseeable effects on fish production (variety and quantity), favouring fishing at new sites or in more remote areas; it was pointed out at the workshops that this issue was not a concern for Québec, but could become one for the neighbouring provinces[9]. In addition, fishing under harsher weather conditions could become a more frequent occurrence. Infrastructures will possibly sustain damage in extreme weather events. All these factors could result in lower revenues and affect fishermen's health and safety [64]. As observed in the United States, the proliferation of blue algae and the emergence of new diseases related to marine toxins [65] would intensify as a result of CC. Although it was reported at the workshops that these risks are probably low for Québec[9], employees who work in seafood harvesting, processing, and shipping could eventually be at risk [65].

Predictions suggest that CC could also affect forest ecosystems by changing the natural disturbance regimes of forests and the dynamics with forest insects. The increased concentrations of tropospheric ozone, which slow down tree growth and predispose them to pathogens, could amplify this phenomenon [for a review, see 66]. As pointed out at the workshops, these upheavals in forests could necessitate the cutting of large quantities of trees over short periods of time, or endanger the forest industry in certain regions, with numerous repercussions on the forestry labour market[9]. The geographic range of toxic plants such as poison ivy, ragweed, and sumac could also increase, subjecting outdoor workers to greater exposure. Schulte and Chun [9] reported that one-third of forestry workers and firefighters who have fought forest fires in the states of California, Oregon, and Washington developed skin rashes or lung irritations following the combustion of Canadian sumacs. This type of risk could undoubtedly apply to outdoor workers such as landscapers, farmers, and road workers.

[9] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

4.1.3 Consequences for the socio-economic context

The third main impact theme was socio-economic, and essentially concerned the degradation of the built environment and the emergence of new "green" industries (Figure 2).

Predictions suggest that CC could impact the efficiency, service life, and safety of infrastructures and buildings. Network services such as energy distribution, roads, and transportation and telecommunication systems could experience breakdowns, thus increasing workers' risk of exposure and vulnerability to new work environments and new hazards [for a review, see 67, 68]. A number of industries that could potentially be affected by CC were identified at the workshops. In the Far North, warmer winters and the melting of the permafrost already appear responsible for major damage to road infrastructures (ice bridges, airstrips) and support systems in mines[10]. This damage could disrupt transportation and increase the risks present in underground mines, as well as the risk of road accidents and drownings. Forestry, mining, and hydroelectric mega-project construction workers were specifically pinpointed at the workshops[10]. Another industry potentially affected by CC and discussed at the workshops is tourism, whose performance depends on climate and the quality of hospitality infrastructures; the rise in water levels in certain coastal regions could, for example, destroy beaches or damage tourism infrastructures, possibly leading to job insecurity among workers in this industry[10].

Predictions also suggest that new industries aimed at reducing or mitigating the impacts of CC by reducing greenhouse gas emissions [69] will emerge over the next few decades. Changes will be made to traditional jobs; new "greener" occupations will be created, and the new challenges faced by industry could generate new physical and chemical risks for workers [3, 14, 70]. Furthermore, some buildings could be built more hermetically to reduce the energy consumed for air conditioning and heating. These more airtight buildings may tend to accumulate various chemical products. In the case of buildings with cellars or underground work spaces, workers could be more exposed to higher concentrations of gases such as radon [9, 71].

Renewable energies, solar energies (including photovoltaic energy), fuel cells (including hydrogen cells), CO_2 capture and storage applications, and new transportation technologies such as electric, hybrid, and diesel vehicles, are "green" fields that could see large-scale developments in the coming decades. These new fields could also have consequences in terms of the emergence of new OHS risks. For example, jobs in the wind power generation sector pose substantial risks, all of which are related to work in confined spaces [72], such that the American Society of Safety Engineers recently deemed it necessary to develop new standards to protect these workers [70]. One of the emerging OHS issues that was discussed at the workshops consists of the use of hydrogen cells as a replacement for diesel fuel, which would improve the quality of air in underground mines but could also increase the risks of explosion[11] Moreover, the production, processing, and recycling of biofuels are activities that create risks of respiratory and

[10] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

[11] Discussions that took place at the workshops. Institut de recherche Robert-Sauvé en santé et en sécurité du travail. Montréal, Québec, Canada. November 24-25, 2010.

inflammatory problems due to the handling of large quantities of microorganisms, fungal spores, endotoxins, and dusts [73, 74, 75].

4.2 Priority research topics

Some thirty potential research topics (Appendix D) were identified through two workshops and a first round of consultation. These were narrowed down to twelve priority research topics through a final consultation. Seventeen individuals were involved in both consultations. These research topics were divided into three major OHS-related categories: the acquisition of knowledge of hazards and target populations, epidemiological surveillance, and the development of adaptation measures.

4.2.1 Research topics related to the acquisition of knowledge of hazards and target populations

→ Study past extreme weather events in order (1) to draw lessons from the type of work involved and (2) develop mitigation strategies.

→ Study and evaluate new OHS hazards related to extreme CC exposures and their potential impacts on infrastructures.

→ Study the increased toxicity and health effects of various biological/chemical agents and materials during episodes of extreme heat, air pollution, drought, or intense rainfall.

→ Assess current and future risks related to aeroallergens and zoonotic diseases (e.g. Lyme's disease, West Nile virus, St. Louis encephalitis, La Crosse encephalitis, Eastern Equine encephalitis).

→ Study the heat stresses and hydric stresses associated with wearing protective clothing and equipment during extreme heat episodes.

→ Identify the categories of workers vulnerable to accidents and diseases associated with CC impacts, considering their working conditions and individual characteristics.

4.2.2 Research topic related to epidemiological surveillance

→ Define accident and disease indicators and collect information allowing for surveillance of the health effects attributable to climate factors.

4.2.3 Research topics related to the development of adaptation measures

→ Identify and evaluate the adaptation measures implemented around the world.

→ Develop training tools to prepare healthcare workers for the potential consequences of climate change, in particular, heat stroke and zoonotic and communicable vector-borne diseases.

→ Develop a range of work clothing and other protective equipment suitable for adaptation to climate variabilities and extremes and that promote their actual use by workers.

→ Explore CC adaptation measures using work organization and schedule management.

→ Develop measures for raising awareness in and informing workplaces (workers and employers) of the potential accident and disease risks associated with climate variabilities, in the short term (e.g. severe thunderstorms and accidents) and long term (e.g. skin cancer and UV radiation).

5. Discussion

The first aim of this study was to provide a general overview of the links between CC and its potentially adverse impacts on OHS in Québec. The literature review performed for this purpose highlighted the hazards associated with CC, their potential impacts on OHS, and the types of industries potentially affected.

Of the articles and documents consulted, only one touched on all the impacts of CC on OHS, namely that of Schulte and Chun [9]. Our study revealed slight differences between the regional Québec-focused evaluation of the relationship between CC and OHS and the conceptual framework developed by Schulte and Chun.

Like Schulte and Chun, our literature review allowed the identification of five types of exposure or hazards that could have direct or indirect impacts on OHS (heat waves, air pollutants, ultraviolet radiation, extreme weather events, and communicable vector-borne and zoonotic diseases). In addition, two other impacts that could have major consequences for the socio-economic context were retained. These are the degradation of the built environment and the emergence of new "green" industries, together with the new occupational risks associated with them. However, unlike Schulte and Chun’s conceptual framework, [9], we identified three additional impacts at the level of natural resources that could modify the work environment. These are changes in agricultural and animal husbandry methods, changes in the fishing industry, and disturbances of the forest ecosystem.

There are various explanations for the differences observed between our framework and that of Schulte and Chun [9]. First, our study focused specifically on potential problems in Québec, while the general framework developed by Schulte and Chun [9] involved a more global perspective. Some of the impacts they identified do not therefore apply to Québec. For example, Québec’s northerly location makes worker exposure to malaria or venomous snake bites unlikely. Second, our consultation with a working group comprising stakeholders from the workplace environments directly concerned by CC clearly helped in our "regional" adaptation of Schulte and Chun’s conceptual framework [9], a process recommended by these authors, by promoting the addition of more specific information.

The other aims of this study concerned the implementation of a working and consultation procedure promoting national and international dialogue and reflection in order to identify priority research topics pertinent to Québec. The formation of a working group and obtention of a consensus on research topics that reflect the perceptions of both scientific experts and stakeholders from Québec’s economic activity sectors have shown the usefulness of this approach.

Based on the discussions and consultations held, it is clear that the acquisition of knowledge on hazards and target populations is a priority research topic for Québec. It is consistent with the emergence of CC issues concerning OHS and with the fact that this subject has never been the focus of specific studies in Québec or any northern industrialized countries with a temperate climate. Furthermore, at the workshops, several stakeholders from Québec’s economic activity sectors admitted that they had never really heard anything in this regard. However, after examining the literature review, they said they were affected by the various issues raised and proceeded to participate actively in the discussions and identification of research topics.

While the process used in our study to establish priority research topics was specific to Québec, it yielded results that are not far removed from the recommendations made by Schulte and Chun [9]. In fact, several of the items listed in their reference framework are very close to our categories of priority research topics, namely the general acquisition of knowledge on the links between CC and OHS, and work on risk communication and on surveillance of the impacts on OHS. For purposes of comparison, the list of research topics resulting from the workshop discussions is included in Appendix D.

5.1 Methodological considerations

Despite the contribution it makes to the identification of links between CC and OHS, this study has certain limitations. First, it focused on CC impacts on OHS and deliberately avoided looking at all the CC impacts on the labour market. Thus, strategies for adapting the labour market in light of CC, the economic impacts of CC, and the detailed impacts of CC on biodiversity or on the integrity of natural resources were excluded, notwithstanding their importance for the work world.

Second, the study concentrated on the adverse effects of CC, while fully recognizing that not all the impacts of CC on OHS will be negative. For example, agricultural and forestry production could be enhanced if pests are controlled, thereby increasing revenues and job numbers in these industries, which in turn could be beneficial for OHS, although revenues and the labour market are not direct determinants of the latter. In addition, certain tourism activities such as golfing, hunting, and fishing could see longer seasons, which would fuel that industry's economy [6], although pressure to reduce greenhouse gases could lead to a smaller influx of tourists via air and land travel [8]. It has even been reported that CC could be favourable to the overall Québec economy and that the capacity to adapt to the new climate context will be a key factor in industries' response to CC [6].

Third, the members of the working group were selected in such a way as to bring experts on the CC impacts identified in the literature together with stakeholders from the economic activity sectors potentially affected by CC. While justified, these choices are probably partly responsible for the fact that very few new hazards or new economic activity sectors were identified at the workshops.

The fact that we selected these particular members to form the working group was also one of the critical components of the Delphi method that was used here to identify the research priorities [76]. It is highly likely that a group comprising stakeholders from other industries and/or economic activity sectors, or other experts, could have identified different research priorities. Also, the priority research topics identified in this study were obtained following two rounds of consultation, whereas additional consultations could conceivably have yielded slightly different results. That said, the consensus on the priority research topics appears acceptable, as the degree of unanimity regarding the choices was high and the excluded items were generally deemed to have less impact, affecting, for example, only one problem specific to only one or two economic activity sectors.

Lastly, the research priorities identified in this study were established at a specific moment in time based on the currently available scientific, political, and economic knowledge. The impacts of CC on future jobs will undoubtedly lead to changes that will require the research agenda to be adapted. For example, international pressure for the development of "greener" industries will lead to changes in the labour market, changes that are already visible in the energy, postal service, and automobile industry sectors in Canada [8]. The research priorities will therefore have to be re-evaluated to reflect this ongoing evolution in knowledge of the impacts of CC, significant changes in the labour market, or major changes in climate projections for Québec.

6. CONCLUSION

Over the next few decades, the global CC context will likely necessitate significant changes in a number of industries and occupations. Sizeable challenges will have to be faced as numerous emerging problems will in all probability impact on the work environment. Each problem will have to be examined taking often-conflicting environmental, social, and economic constraints into account. With this in mind and in light of the results obtained in this study, the research group considers that further studies are warranted with respect to the three main priority orientations: the acquisition of knowledge on hazards and target populations, epidemiological surveillance in collaboration with public health partners, and the development of adaptation measures.

BIBLIOGRAPHY

1. Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_fr.pdf. Accessed October 01, 2010.

2. Séguin, J. 2008. Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity, 546, Health Canada, Ottawa (Canada).

3. Rosenthal, J. and C. Jessup. 2009. Global Climate Change and Health: Developing a Research Agenda for t*he NIH. Trans Am Clin Climatol Assoc*. 120: 129–41.

4. United Nations Environment Programme/Sustainlabour, 2008. Climate Change, its Consequences on Employment and Trade Union Action: Training manual for workers and trade unions. http://www.unep.org/labour_environment/PDFs/training/CC-COVERTOINTRO-FR.pdf. Accessed October 01, 2010.

5. D'Amato, G and L. Cecchi. 2008. Effects of climate change on environmental factors in respiratory allergic diseases. *Clin Exp Allergy*. 38(8): 1264-74.

6. Desjarlais, C. et al. 2010. Learning to adapt to Climate Change. OURANOS, Montréal. http://www.ouranos.ca/ media/nouvelle/ document/53_sscc_21_06_lr.pdf Accessed October 01, 2010.

7. World Health Organization. 2005. Gender, climate change and health- Draft discussion paper.http://www.who.int/globalchange/publications/reports/final_who_gender.pdf Accessed October 01, 2010.

8. Lipsig-Mumme, C. et al. 2010. What do we know? What do we need to know? The Implications of Global Climate Change for Canadian Work and Employment. Work in a Warming World Research Programme. http://www.workinawarmingworld.yorku.ca/projects/what-do-we-know-what-do-we-need-to-know/ Accessed January 30, 2012.

9. Schulte, P. and Chun, H. 2009. Climate Change and Occupational Safety and Health: Establishing a Preliminary Framework. *J Occup Environ Health*. 6: 542–54.

10. Harrington, J.M. 1994. Research priorities in occupational medicine: a survey of United Kingdom medical opinion by the Delphi method. *Occup Environ Med.*51: 289-94.

11. LoVecchio, F. et al. 2007. Outcomes after environmental hyperthermia *Am J Emerg Med*. 25(4): 442-4.

12. National Oceanic and Atmospheric Administration. 2010. Heat waves. A major summer killer. http://www.nws.noaa.gov/om/brochures/heatwave.pdf Accessed October 01, 2010.

13. Intergovernmental Panel on Climate Change (IPCC). 2007. Working Group II Report "Impacts, Adaptation and Vulnerability" Chapter 8: Human Health. http://www.ipcc.ch/ipccreports/ar4-wg2.htm Accessed October 01, 2010.

14. Tanaka, M. 2007. Heat Stress Standard for Hot Work Environments in Japan. *Ind Health*. 45: 85–90.

15. Kjellstrom, T. et al. 2009. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. *Glob Health Action*. 2: 10-7.

16. Canadian Centre for Occupational Health and Safety (CCOHS). 2011. « Humidex Rating and Work » Canadian Centre for Occupational Health and Safety http://www.cchst.ca/oshanswers/phys_agents/humidex.html Accessed August 31, 2011.

17. Kjellstrom, T. et al. 2010. Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. *Int J Public Health*. 55: 97–103.

18. Gordon, C.J. 2005. Chapter 7. Environmental stress, in Temperature and toxicology. An integrative comparative and environmental approach. Taylor and Francis, Boca Raton. Florida. p. 195-231.

19. Gordon, C.J. 2005. Chapter 4. Temperature effects on chemical toxicity, in Temperature and toxicology. An integrative comparative and environmental approach. Taylor and Francis, Boca Raton. Florida. p. 107-41.

20. Ramsey, J.D. 1995. Task performance in heat: a review. *Ergonomics*. 38: 154-65.

21. Ramsey, J.D. et al. 1983. Effects of workplace thermal conditions on safe work behaviour. *J Saf Res*. 14 (3): 105-14.

22. Tawatsupa, B. et al. 2010. The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers. *Glob Health Action*. 3: 10-20.

23. Grandjean A.C. and N.R. Grandjean. 2007. Dehydration and cognitive performance. *J Am Coll Nutr*. 26(5 Suppl): 549-54.

24. Statistics Canada. 2011. Table 102-0540 – Deaths by age group and sex, Canada, provinces and territories, annual, 1974 to 2008. CANSIM (database) http://www5.statcan.gc.ca/cansim/a01?lang=fra Accessed August 31, 2011.

25. Letard, M. et al. 2004. La France et les Français face à la canicule: les leçons d'une crise [France and the French facing the heat wave: lessons from a crisis]. France- French

Senate, Special Information report No 195; French Senate 2003-2004 sessions. http://www.senat.fr/rap/r03-195/r03-1951.pdf Accessed October 1, 2010.

26. Centers for Disease Control and Prevention. 2008. Heat-Related Deaths Among Crop Workers, United States, 1992-2006. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5724a1.htm Accessed October 1, 2010.

27. Marszałek, A. et al. 2005. Assessment of work ability in a hot environment of workers of different ages. *Int Congress Ser*. 1280 : 208-13.

28. Jay, O. and G.P. Kenny. 2010. Heat exposure in the Canadian workplace. *Am J Ind Med*. 53(8): 842-53.

29. Park, E-K. et al. 2009. Use of Personal Protective Equipment in Agricultural Workers under Hot and Humid Conditions- Letter to editor. *Ind Health*. 47: 200–1.

30. Bernard, T.E. 1999. Heat stress and protective clothing: An emerging approach from the United States. *Ann Occup Hyg*. 43(5): 321-7.

31. Walker, S.M. et al. 2001. The combined effect of heat and carbon monoxide on the performance of motorsport athletes. *Comp Biochem Physiol A Mol Integr Physiol*. 128(4): 709-18.

32. U.S. Department of Labor. Mine Safety and Health Administration. 2010. Heat Stress in Mining. http://www.msha.gov/s&hinfo/heatstress/manual/heatmanual.htm Accessed October 01, 2010.

33. Morioka, I. et al. 2006. Hot environment and health problems of outdoor workers at a construction site. *Ind Health*. 44(3): 474-80.

34. Noweir, M.H. et A.O Bafail. 2008. Study of summer heat exposure at the ground services operations of *a main in*ternational airport in Saudi Arabia. *Environ Monit Assess*. 145(1-3): 103-11.

35. Crowe, J et al. 2009. A pilot field evaluation on heat stress in sugarcane workers in Costa Rica: What to do next? *Glob Health Action*. 11 (2): 1-10.

36. Brauer, M. et al. 1996. Effect of ambient ozone exposure on lung function in farm workers. *Am J Respir Crit Care Med*. 154(4 Pt 1): 981-7.

37. Peden, D and C.E. Reed. 2010. Environmental and occupational allergies. *J Allergy Clin Immunol*. 125 (2) suppl-2. 150-60.

38. Cheng, M-F. et al. 2007. Air Pollution and Hospital Admissions for Pneumonia in A Tropical City: Kaohsiung, Taiwan. *J Toxicol Environ Health, Part A*. 70: 2021–6.

39. Ayres, J.G. et al. 2009. Air pollution and asthma severity in adults. *Occup Environ Med*. 66: 182–8.

40. Apte, M.G. et al. 2007. Outdoor ozone and building related symptoms in the base study. *Indoor Air* .18(2): 156-70.

41. Dominici, F. et al. 2006. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA*. 295 (10): 1127-34.

42. Goldberg, M.S. et al. 2001. Identification of persons with cardiorespiratory conditions who are at risk of dying from the acute effects of ambient air particles, *Environ. Health Perspect.* 109 (suppl. 4): 487-94.

43. Cohen, A.J. et al. 2005. The global burden of disease due to outdoor air pollution. *J Toxicol Environ Health, Part A*. 68: 1–7.

44. Lucas, R.M. et al. 2008. Estimating the global disease burden due to ultraviolet radiation exposure. *Int J Epidemiol*. 37: 654–67.

45. Gallagher, R.P. et T.K. Lee. 2006. Adverse effects of ultraviolet radiation: A brief review. *Prog Biophys Mol Biol*. 92: 119-31.

46. Canadian Centre for Occupational Health and Safety (CCOHS). 2011. Skin Cancer and Sunlight » Canadian Centre for Occupational Health and Safety. http://www.cchst.ca/oshanswers/diseases/skin_cancer.html Accessed August 31, 2011 2011.

47. Centers for Disease Control and Prevention 2010. NIOSH Workplace Safety and Health Topics- UV radiation. http://www.cdc.gov/niosh/topics/uvradiation/ Accessed October 01, 2010.

48. National Agricultural Safety Database. 2002. The dark side of the sun: Sun exposure and Agriculture. http://nasdonline.org/document/928/d000769/the-dark-side-of-the-sun-sun-exposure.html Accessed October 01, 2010.

49. Arcury, T.A. et al. 2006. Treating Skin Disease : Self-Management Behaviors of Latino Farmworkers. *J Agromed*. 11(2): 27-35.

50. Wheaton, E. et al. 2007. Agricultural Adaptation to Drought (ADA) in Canada - The case of 2001-2002. Gouvernement du Canada - Climate change impacts and Adaptation programs.http://www.cciarn.uoguelph.ca/documents/agri_adapt_cc.pdf Accessed October 01, 2010.

51. Tak, S. et al. 2007. Floodwater exposure and the related health symptoms among firefighters in New Orleans, Louisiana. *Am J Ind Med.* 50(5): 377-82.

52. Tak, S. et al. 2007. Depressive symptoms among firefighters and related factors after the response to Hurricane Katrina. *J Urban Health*. 84(2): 153–61.

53. Morgan, E.R. and R. Wall. 2009. Climate change and parasitic disease: farmer mitigation? *Trends Parasitol*. 25 (7): 308-13.

54. Gale, P. et al. 2009. The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: a review. *J Appl Microbiol*. 106: 1409–23.

55. Boxall, A.B.A. et al. 2009. Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture. *Environ Health Perspect*. 117 (4): 508-14.

56. Ogden, N.H. et al. 2009. The emergence of Lyme disease in Canada. *Can Med Assoc J*. 180(12): 1221-4.

57. National Institute for Occupational Safety and Health (NIOSH). 2005. Recommendations for protecting outdoor workers from West Nile Virus Exposure http://www.cdc.gov/niosh/docs/2005-155/ Accessed October 01, 2010.

58. CPWR - The Center for Construction Research and Training. 2002. Hazard Alert. Lyme disease in Construction. http://www.elcosh.org /en/document/1/d000001/hazard-alert%253A-lyme-disease-in-construction.html. Accessed October 01, 2010.

59. Centers for Disease Control and Prevention. 2010. NIOSH Workplace Safety and Health Topics-Tick borne disease. http://www.cdc.gov/niosh/topics/tick-borne/ Accessed October 01, 2010.

60. Sverke, M. et al., 2002. No security: A meta-analysis and review of job insecurity and its consequences. *J Occup Health Psychol.* 7(3): 242-64.

61. Chakraborty, S. et al. 2008. Impacts of Global Change on Diseases of Agricultural Crops and Forest Trees. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. http://pdf.usaid.gov/pdf_docs/PNADP262.pdf Accessed October 01, 2010.

62. Mantell S. and P. Van Hove. 2008. Briefing: Agriculture and development. http://about.greenfacts.org/pressroom/press-book/popup/080925-civil-engineer.pdf Accessed October 01, 2010.

63. Marrachi, G. et al. 2005. Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Clim Change*. 70: 117–35.

64. Food and Agriculture Organization of the United Nations. 2008. FAO Expert Workshop on Climate change implications for fisheries and aquaculture. ftp://ftp.fao.org/docrep/fao/010/i0203e/i0203e00.pdf Accessed October 01, 2010.

65. Fleming, L.E. et al. 2006. Oceans and human health: Emerging public health risks in the marine environment. *Mar Pollut Bull*. 53(10-12): 545–60.

66. Evans, A. M. et R. Perschel. 2009. A review of forestry mitigation and adaptation strategies in the Northeast U.S. *Clim Change*. 96:167–83

67. Infrastructure Canada. 2006. Adapting infrastructure to climate change in Canada's cities and communities- a literature review. http://cbtadaptation.squarespace.com/storage/CdnInfrastructureAdaptation-LiteratureReview.pdf Accessed October 1, 2010.

68. Baker, C.J. et al. 2009. Climate change and the railway industry: a review. *J Mech Eng Sci.* 224 (3): 519-28.

69. United Nations of Environment Program, 2008. Green Jobs: Towards decent work in a sustainable, low-carbon world.http://www.unep.org/labour_environment/PDFs/Greenjobs/UNEP-Green-Jobs-Report.pdf Accessed October 01, 2010.

70. Centers for disease control and prevention (CDC). 2010. Prevention through design; Green, safe and healthy jobs. http://www.cdc.gov/niosh/topics/ptd/greenjobs.html Accessed October 01, 2010.

71. Li, X. et al. 2006. A survey of radon level in underground buildings in China. *Env Int*. 32: 600–5.

72. Occupation Health and Safety. 2009. Cultivating safety at wind farms. http://ohsonline.com/articles/2009/01/01/cultivating-windfarms.aspx Accessed October 01, 2010.

73. Madsen, A. et al. 2006. Characterization of Microbial Particle Release from Biomass and Building Material Surfaces for Inhalation Exposure Risk Assessment. *Ann Occup Hyg*. 50 (2): 175-87.

74. Madsen, A.M. 2006. Exposure to Airborne Microbial Components in autumn and spring during Work at Danish Biofuel plants. *Ann Occup Hyg*. 50 (8): 821-31.

75. Madsen, A.M. et al. 2009. Airborne Fungal and Bacterial Components in PM1 Dust from Biofuel Plants. *Ann Occup Hyg*. 53 (7): 749-57.

76. Iavicoli, S. et al. 2006. Research priorities in occupational safety and health: a review. *Ind Health*. 44(1): 169-78.

APPENDICES

Appendix A: Members of the research team

Name	Institutions - Affiliations	Expertise
Joseph Zayed Principal investigator	Full professor, Université de Montréal; Research Field Leader, Chemical Substances and Biological Agents, IRSST	Toxicology Environmental and occupational health Exposure science and risk analysis
Audrey Smargiassi Co-investigator	Chair on Air Pollution, Climate Change, and Health; Assistant clinical professor, Université de Montréal	Assessment and estimation of environmental health risks Exposure science (large populations)
France Labrèche Co-investigator	Researcher, IRSST; Assistant clinical professor, Université de Montréal	Occupational health epidemiology Study of occupational cancer
Patrice Duguay Contributor	Professional research scientist Coordinator, Statistical Knowledge and Surveillance Group, IRSST	Indicators and characteristics of compensated work-related injuries Target populations and problems
Marc-Antoine Busque Contributor	Professional research scientist IRSST	Indicators and characteristics of compensated work-related injuries Target populations and problems
Ariane Adam-Poupart Contributor	Research officer Université de Montréal	Environmental and occupational health, Ph.D. student in toxicology and risk assessment
Charles Gagné Contributor	Knowledge Transfer Advisor, IRSST	Transfer and application of research results

Appendix B: Identification of publications used for the literature review

Initial search: **15,097 articles**

Exclusion of

1. Commentaries, editorials, news, personal opinion letters, questions-answers.
2. Articles in light of relevance of their titles.

Articles tentatively retained = **599 articles**

Exclusion of articles published before 2005 (except 10 articles)

Articles tentatively retained and published between 2005 and 2010 = **497 articles**

Exclusion of articles

1. Not related to occupational health and safety or climate change
2. Related to risks not present in Québec
3. Related to exposure to extreme cold
4. In languages other than English or French

Articles ultimately retained = **209 articles**

Inclusion of other information sources
IPCC, EPA, WHO, NHS, CDC, US Army, OURANOS (Québec consortium on climate change), Canadian government (HC, EC and NRC), UNEP, NIOSH.

209 articles and
information from approximately ten websites were used for purposes of the literature review.

Appendix C: Members of the Panel of Experts

Nom	Institutions – Affiliations	Expertise
Bourque, Alain	Researcher, OURANOS (Consortium on Regional Climatology and Adaptation to Climate Change)	1. Climate analysis 2. Impacts and adaptation to climate change
Kjellstrom, Tord	Professor, Visiting Fellow, National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia Honorary Professor, UCL, London Senior Professor, Umea University, Sweden	3. Epidemiology and environmental and occupational health, air pollution, and toxic metals 4. Health and transportation 5. Climate change and health 6. Impacts of workplace heat exposure 7. Global and urban health analysis
Notebaert, Éric	Hôpital Sacré-Coeur de Montréal Associate clinical professor, Université de Montréal Comité Santé-Environnement, Collège des Médecins de Famille du Québec Canadian Association of Physicians for the Environment	8. Emergency medicine; critical care 9. Toxicology
Rhainds, Marc	Physician specializing in UV radiation INSPQ	10. Ultraviolet radiation 11. Dermatology and skin cancer 12. Environmental health 13. Public health; epidemiology
Rintamäki , Hannu	Professor and Physical Work Capacity team leader, Finnish Institute of Occupational Health, Oulu, Finland Institute of Biomedicine, Department of Physiology, University of Oulu, Finland	14. Thermal physiology 15. Physical Work capacity 16. Strain and health in various climatic conditions and occupations
Vaillancourt, Jean-Pierre	Full professor, Faculty of Veterinary Medicine – Clinical Sciences Université de Montréal	17. Epidemiology 18. Veterinary medicine 19. Vector-borne diseases
Villeneuve, Claude	Full professor, Université du Québec à Chicoutimi	20. Climate change 21. Environmental sciences; biodiversity

Appendix D: List of research topics resulting from workshop discussions

1. Study boat designs that would take into account the impacts of climate change and OHS (e.g. stability, covered bridges to protect against UV radiation).
2. Study and assess the new OHS risks and impacts resulting from exposure to extreme conditions: erosion, melting permafrost, and its effects (e.g. danger of explosion associated with release of methane, ground subsidence).
3. Participate in activities associated with the project aimed at promoting the safe use of hydrogen in underground mining operations (e.g. work on regulations, OHS aspects of the pilot implementation study in a mine, validation of safety measures).
4. Study the rise in water levels in northern Québec and its potential impact on the OHS of workers in deep-water ports.
5. Study the impacts of the increase in extreme-heat episodes on air conditioning in mines (outside air used to ventilate mines).
6. Study the impacts of extreme heat on "re-entry" periods in agricultural and forestry work environments, taking into account the increased volatility of pesticides (e.g. changes in dermal absorption, inhalation parameters, and respiratory rates).
7. Explore the hazard related to zoonotic diseases in workers exposed to animals and insects (e.g. Lyme's disease, West Nile virus, St. Louis encephalitis, La Crosse encephalitis, Eastern Equine encephalitis).
8. Study the hazards of worker exposure to combustion dusts associated with the salvaging of burnt timber and the reforestation of burn areas, in view of the potential increase in forest fires.
9. Study the heat stress associated with clothing and protective equipment (e.g. masks, hazmat suits, helmets, coveralls) during periods of extreme heat.
10. Develop methods for raising awareness in and informing workplaces (workers and employers) of the potential risks of climate change, particularly the long-term risks (e.g. skin cancer and UV radiation).
11. Explore measures for adapting to climate change that involve work organization (e.g. for hazards associated with faster work paces adopted to "finish the work before the storm," possibilities of slowing down the work pace during periods of extreme heat without affecting productivity or the service offered).
12. Verify whether the use of "greener" materials poses any additional health risks compared to traditional materials.

13. Study the increase in toxicity, hazardousness, and effects of certain biological and chemical products and materials during periods of extreme heat and significant air pollution.

14. Explore the problem of bacterial and viral proliferation for workers (confined spaces or other work environments) associated with heat or heavy rainfall.

15. Identify and evaluate the mitigation strategies implemented in other countries.

16. Study heat stress in light of the physical workload of wind power workers (e.g. going up and down ladders, carrying heavy loads, working in confined spaces).

17. Study the health risks to workers during refurbishing operations on nuclear power plants.

18. Define indicators for and promote surveillance of the impacts of climate (e.g. heat stroke, accidents as secondary effects of heat).

19. Develop training tools to prepare workers in the healthcare sector for the consequences of climate change, particularly heat stroke and zoonotic and vector-borne diseases.

20. Describe visits to emergency departments in order to identify those related to the impacts of climate change on workers (particularly in connection with heat and zoonotic and vector-borne diseases).

21. Study some of the extreme weather events that have occurred in the past in Québec or elsewhere in the world to derive lessons on how to handle and prepare for such events.

22. Identify the categories of workers vulnerable to the impacts of climate change—the highest-risk sub-sectors or occupations, individuals at the highest risk due to personal conditions (e.g. age, medications)—and inform and monitor the persons concerned.

23. Study the intensity of already known risks and the capacities for adapting to these risks.

24. Assess needs in terms of building construction and adaptation to ensure better designs to cope with climate change (e.g. insulation for more efficient air conditioning).

25. Develop clothing and other protective equipment that are better adapted to hotter temperatures (e.g. new materials, helmet colour) to promote their actual use by workers.

26. Study workplace cultures in order to influence and change risky behaviours with regard to UV radiation.

27. Develop methods for alerting workers and employers in real time of the short-term hazards of climate change (e.g. how to convey the hazards of extreme heat in a simple, clear, and prompt manner).

28. Document and quantify work-related injuries associated with past exposure to climate change (e.g. heat waves or periods of smog). Then, generate worker morbidity and mortality models in light of future climate simulations.

29. Identify new aeroallergens, pathogens responsible for zoonotic diseases, and marine toxins that could migrate to Québec.

30. Analyze the adaptation measures, taking into account various aspects of multiple constraints and ensuring that the mitigation of one constraint does not generate another constraint (e.g. personal protective equipment that increases heat stress).