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Adapting to vector-borne diseases under climate change: an evidence-informed approach

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RÉSUMÉ

Les preuves s'accumulent sur les effets des changements climatiques. Étant donné leurs impacts sur la santé, en particulier sur les maladies à transmission vectorielle, il est nécessaire de concevoir des stratégies efficaces pour adapter les programmes de gestion de risque de ces maladies. Les changements climatiques constituent un problème complexe, impliquant de multiples parties prenantes et comportant beaucoup d'inconnues. Des approches qui prennent en compte cette complexité sont ainsi nécessaires afin de faire avancer la recherche sur l'adaptation aux changements climatique basée autant sur des données scientifiques que sur des données provenant de différents intervenants. Les approches fondées sur les données probantes sont de plus en plus recherchées dans les politiques de santé et la prise de décisions, dans le but d'améliorer la santé des populations. Ces approches sont apparues en réaction aux approches improvisées, développées suite aux crises liées aux problèmes de santé publique. Elles doivent être systématiques et transparentes, et faire appel aux meilleures preuves disponibles. L'aide à la décision multicritère délibérative constitue une de ces approches.

L'objectif de cette thèse était d'étudier les principales préoccupations en matière de décisions relatives à l'adaptation au risque des maladies vectorielles influencées par les changements climatiques dans deux contextes : le Québec, où les maladies vectorielles sont présentes, mais ne constituent pas la principale préoccupation, et le Burkina Faso, où les maladies vectorielles sont au contraire très préoccupantes. Les fondements théoriques de cette étude sont basés sur la science post-normale, l'adaptation aux changements climatiques et une approche d'analyse de décision multicritère. La recherche sur l'adaptation aux

changements climatiques vise à influencer les politiques cherchant à réduire les risques et les impacts associés à ces changements. Dans ce cadre et dans le contexte de l'adaptation aux maladies vectorielles, trois questions clés se posent : 1) de quelles maladies nous préoccupons-nous ? 2) qui est le plus vulnérable à ces maladies ? et 3) quelles sont les mesures recommandées pour s'adapter à ces maladies ? Cette thèse contribuera à répondre à ces trois questions dans le but de faire avancer l'adaptation face aux maladies vectorielles.

Pour répondre à la première question, nous avons identifié des préoccupations d'importance pour la priorisation des maladies liées aux changements climatiques au Québec et au Burkina Faso grâce à l'utilisation d'une approche délibérative multicritère d'aide à la décision. Les résultats ont démontré que, alors que des préoccupations générales sont partagées entre ces deux régions, des préoccupations plus spécifiques aux maladies diffèrent quant à elles selon le contexte, tant sur des aspects scientifiques que sur d'autres aspects partagés par les parties prenantes.

Pour répondre à la deuxième question, les connaissances actuelles et les comportements de la population québécoise quant au virus du Nil occidental ont été explorés, comme étape préliminaire pour évaluer la capacité d'adaptation au risque de maladies causées par les moustiques. Nous avons considéré que la réponse au risque perçu de maladies transmises par les moustiques constituait une forme d'adaptation. Les résultats ont montré que les connaissances globales et les niveaux d'adoption comportementale sont bons et qu'il existe au moins quatre sous-groupes différents dans la population caractérisés par différents facteurs associés à l'adoption de comportements préventifs.

Enfin, pour répondre à la troisième question, une approche multicritère délibérative a été utilisée pour examiner les stratégies de gestion du virus du Nil occidental au Québec, dans le cadre théorique d'une transmission accrue, et les

stratégies de gestion du paludisme au Burkina Faso, dans le cadre de la transmission actuelle. De manière analogue au modèle développé pour la priorisation des maladies, cette comparaison entre les deux régions et les contextes de maladie ont permis de confirmer l'existence de préoccupations générales partagées. Cette thèse a permis de démontrer la pertinence des approches d'aide à la décision pour explorer des stratégies de gestion efficaces basées sur l'expérience des intervenants et les meilleures preuves scientifiques disponibles.

Mots-clés : Adaptation aux maladies vectorielles, changements climatiques, virus du Nil occidental, paludisme, approches fondées sur des données probantes, aide multicritère à la décision, Québec, Burkina Faso

ABSTRACT

Evidence is accumulating on the ongoing effects of climate change. Given the anticipated health implications, notably vector-borne disease impacts, there is a need to design effective and tailored strategies to adapt *to vector-borne disease risk*. Climate change is a complex problem, involving multiple stakeholders and many unknowns. As such, approaches that can embrace this complexity are needed to inform adaptation research with evidence - both scientific and stakeholder-informed. Evidence-informed approaches are being increasingly sought in health policy and decision-making in order to improve population health. Evidence-informed approaches have arisen in reaction to ad-hoc, crisis-driven responses to health problems. They recognize the need to be systematic and transparent, and make use of the best available evidence. Deliberative multicriteria decision aid is one such approach.

The objective of this thesis was to study key decision concerns of importance in adapting to vector-borne disease risk under climate change in two contexts: Quebec, where vector-borne diseases are present but not the main burden of disease, and Burkina Faso, where vector-borne diseases contribute to the primary burden of disease. The theoretical underpinnings of this study are rooted in post-normal science, climate change adaptation, and a multicriteria decision analysis approach.

Climate change adaptation research is aimed at informing policies to reduce risks and impacts associated with climate change. Within this framework, and in the context of vector-borne disease adaptation, three key questions arise: 1) what diseases are we concerned about? 2) who is most vulnerable and at risk to these diseases? and 3) what are recommended measures to adapt to these

diseases? This thesis contributes to these three dimensions to inform adaptation to vector-borne disease. With regards to the first question, we identified concerns of importance for disease prioritization under climate change in both Quebec and Burkina Faso using a deliberative multi-criteria decision aid approach. The results showed that general concerns are shared among these contrasting contexts while specific disease priorities differ as a result of context-informed evidence – both scientific and stakeholder-shared.

With regards to the second question, current knowledge and readiness of the Quebec population relative to West Nile virus was explored as a preliminary and integral step to assessing adaptive capacity to mosquito-borne disease risk. Here, response to perceived mosquito-borne disease risk constitutes a form of adaptation. The results showed that overall knowledge and behavioural adoption levels are good though at least four different subgroups exist within the population with different factors associated with preventive behaviour adoption.

Finally, with respect to the third question, a deliberative multi-criteria approach was used to examine management strategies for West Nile virus in Quebec and malaria in Burkina Faso. West Nile virus strategies under current and theoretical increased transmission were explored in Quebec, and malaria management strategies under current transmission were explored in Burkina Faso. Analogously to the model developed for disease prioritization, shared general concerns were found between the contrasting country and disease contexts lending support to the practical applications of decision-aid approaches for exploring effective management strategies informed by stakeholder experience and the best available scientific evidence.

Keywords : Vector-borne disease adaptation, Climate change, West Nile virus, malaria, evidence-informed approaches, multi-criteria decision analysis, Quebec, Burkina Faso.

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ACT – Artemisinin-based combination therapy
AEC – Animal and Environmental Health Criteria
AR5 – IPCC Fifth Assessment Report
BF – Burkina Faso
C – Celsius
CC – Climate change
CDC – Centers for Disease Control and Prevention
CHIKV - Chikungunya
CO2 – Carbon dioxide
CNRFP – national research and training center for malaria
CSID – Climate sensitive infectious disease
DALYs – disability-adjusted life years
DEET – diethyltoluamide
DENV - dengue
EBM – Evidence-based medicine
EBPH – Evidence-Based Public Health
ECC – Economic criteria
EIPH – Evidence-Informed Public Health
ENSO – El Niño Southern Oscillation
GAIA - Geometrical analysis for interactive aid
GRP - Group
HBM – Health Belief Model
HDI – Human development index
IPCC – intergovernmental panel on climate change
IPTp – Intermittent treatment for pregnant women
IRS – indoor residual spraying
LD – Lyme disease
LF – lymphatic filariasis
LLIN – Long lasting insecticidal nets
LSM – larval source management
MAL – malaria
MBD – mosquito-borne disease
MCA – multiple correspondence analysis
MCDA – multi-criteria decision aid / multi-criteria decision analysis
Med - Medium
NCCMT - National Collaborating Centre for Methods and Tools
NGO – Non-governmental organization

OTC – over the counter
PH – Public Health
PHA – Public Health Authority
PHC – Public Health Criteria
Phi – net outranking flow
PNLP – national program against malaria
PPM – personal protective measure
PROMETHEE - Preference Ranking Organization Method for Enrichment Evaluations
QALY – quality-adjusted life years
QC - Quebec
RDT - Rapid diagnostic test
REC – Risk and Epidemiology criteria
RNA – Ribonucleic acid
Rnk – rank
RPM – Recommended preventive measures
RR1 – risk region 1
RR2 – risk region 2
S1-S10 - Stakeholders
SIC – Social Impact Criteria
SMC – seasonal malaria chemoprevention for children
SOC – Strategic and Operational Criteria
spp - species
U.S. – United States of America
USAID – United States Agency for International Development
VBD – vector-borne disease
VBZD – vector-borne and zoonotic disease
WBD – water-borne disease
WHO – World Health Organization
WNV – West Nile virus

Chapter specific abbreviations

Chapter 2
AEC-01 – Incidence of animal cases
AEC-02 – Severity of disease
AEC-03 – Environmental or animal reservoir stage
ECC-01 – Cost to government
ECC-02 – Cost to private sector
ECC-03 – Cost to individuals
PHC-01 – Current Incidence of human cases in country
PHC-02 – Severity of the disease (both physically and mentally)
PHC-03 – Vulnerable groups
PHC-04 – Potential to increase social inequality

REC-01 – Existence of favourable conditions for disease transmission
REC-02 – Epidemic potential
REC-03 – Current global trend of disease over last 5 years
REC-04 – Proportion of susceptible population
SIC-01 – Risk perception of the public
SIC-02 – General level of knowledge, attitude and behaviour of the public
SOC-01 – Capacity to detect and diagnose
SOC-02 – Existence and effectiveness of current treatments
SOC-03 – Level of scientific knowledge of the disease
SOC-04 – Optimization opportunities
SOC-05 – Reportable disease

Chapter 3
AEC1 – Animal health impact
AEC2 – Environmental impact
ECC1 – Government cost
ECC2 – Individual and family cost
ECC3 – Cost born by external donors
PHC1 – Current Incidence of human cases in country
PHC2 – Severity of the disease
PHC3 – Physical health impact
PHC4 – Mental health impact
PHC5 – Social equity
SIC1 – Public acceptance
SIC2 – Impact to credibility
SOC1 – Delay
SOC2 – Complexity
SOC3 – Sustainability
SOC4 – Other policy impact

Chapter 5
AEC1 – Animal health Impact
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ECC1 – Government cost
ECC2 – Municipal cost
ECC3 – Individual cost
INT-1 – Use of mosquito repellent
INT-2 – Use of domestic insecticides
INT-3 – Use of alternative technologies
INT-4 – Wearing light colored, long clothing
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INT-6 – Reinforcing the immune system
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INT-8 – Human vaccination

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PHC2 – Entomological risk reduction
PHC3 – Physical health impact
PHC4 – Mental health impact
PHC5 – Social equity
PHC6 – Reduction of circulating virus
PHC7 – Proportion affected
SIC1 – Public acceptance
SIC2 – Impact to credibility
SOC1 – Delay
SOC2 – Complexity
SOC3 – Sustainability
SOC4 – Other policy impact

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INT-I5 – Use and inspection of window screens
INT-I6 – Human vaccination

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PHC2 – Entomological risk reduction
PHC3 – Differential diagnostic
PHC4 – Physical health impact
PHC5 – Mental health impact
PHC6 – Social equity
PHC7 – Proportion affected
SIC1 – Public acceptance
SIC2 – Impact to credibility
SIC3 – Public awareness
SOC1 – Delay
SOC2 – Complexity
SOC3 – Sustainability
SOC4 – Other policy impact

To my family.

"We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at its end lies disaster. The other fork of the road — the one less traveled by — offers our last, our only chance to reach a destination that assures the preservation of the earth."

Rachel Carson

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INTRODUCTION

Over the last decades, climate change has warmed global land surface and ocean temperatures by approximately 0.78°C, with greater warming occurring in the northern hemisphere and mid-to high-latitude areas (IPCC, 2013a). Climate change poses an important risk to human health as a result of 1) direct health effects due to extreme weather events (e.g. heat waves, droughts, heavy rainfall, floods), 2) effects moderated by natural systems that increase human health risks (e.g. disease vectors, water systems and air pollution), and 3) effects moderated by human systems (e.g. occupational effects, food security, psycho-social effects) (Confalonieri et al., 2007; Costello et al., 2009; Smith et al., 2014). Global observations of the effects of climate change have already begun with increased heat related deaths, notably in Europe, (IPCC, 2014; Patz et al., 2005), sea level rise and increased flooding in some regions (IPCC, 2013a), and desertification and water scarcity in parts of Africa (Iglesias et al., 2007; IPCC, 2013b), with the later two effects strongly contributing to exacerbating food security issues in this region. While climate change is a global phenomenon, the impacts have not and will not be evenly distributed, with some of the most vulnerable populations and those having least contributed to climate change suffering some of the greatest impacts (IPCC, 2014).

Climate change and vector-borne diseases have been highlighted as priority risks by the World Health Organization (WHO, 2017a). Changes in the distribution of some vector-borne diseases have already been observed (IPCC, 2014); however, challenges remain in clearly separating the role of climate change from other important drivers of disease risk. Vector-borne diseases are particularly sensitive to changes in weather and climate given the inability of

arthropod vectors and infectious agents to regulate their internal temperature which directly impacts their survival and reproduction (Githeko et al., 2000). Vector-borne diseases currently contribute significantly to the global burden of disease, and as such, further changes in distribution and incidence are a pressing global concern. Given the accumulated levels of greenhouse gases in the atmosphere (Matthews and Caldeira, 2008; Solomon et al., 2009), the world is committed to an inevitable degree of climate change over the upcoming decades and, as such, it is essential to develop adaptation strategies to reduce the negative impacts of climate change and vector-borne disease on health.

Canada and parts of Africa are geographical and socio-economical contrasts offering potential extremes in terms of anticipated impacts of CC and means of coping with the resulting impacts. Both regions are likely to be impacted by changes to vector-borne disease as a result of climate change. In Canada, CC predictions include increased frequency of extreme weather events, natural hazards, reduced air quality, stratospheric ozone depletion and occurrence of some communicable diseases (Seguin, 2008; Warren and Lemmen, 2014). Changes in ice cover, permafrost, flora and fauna have been observed in Canada's arctic (Ford et al., 2008; Fraser et al., 2011; Gardner et al., 2011; Harper et al., 2012, 2015). In Sub-Saharan Africa, evidence of warming has been observed via water stress exacerbating existing vulnerabilities of agricultural systems (Niang et al., 2014). In North America, heavy rainfall, flooding and warm temperatures can favour and increase breeding space for pathogens and vector species such as mosquitoes (Gubler, 2008; Jones et al., 2008; Rose et al., 2001) and have been linked to water-borne (WBD) and vector-borne disease (VBD) outbreak events such as *Escherichia coli (E. coli)* and western equine encephalitis in parts of North America (Auld et al., 2004; Sellers and Maarouf, 1993). In Sub-Saharan Africa, interacting stressors complicate attribution of VBD changes to

climate but evidence has been accumulating on the likely impacts of CC on diseases such as malaria and leishmaniasis among others (Niang et al., 2014).

Climate change has been dubbed a “wicked problem” due to the inherent complexity, high levels of uncertainty and multiple actors with potentially divergent viewpoints requiring consideration (FitzGibbon and Mensah, 2012; Head, 2008). Examining vector-borne diseases under climate change adds to this complexity as a result of its multiple interacting components (both biological and non-biological) which contribute to vector-borne disease risk (Parham et al., 2015b). The differing capacity (i.e. state of public health services) of various countries and regions to react to changes in vector-borne disease transmission further contributes to obscuring the link between climate change and vector-borne diseases (Parham et al., 2015a). While relationships between weather and vector-borne disease occurrence have been observed, disease dynamics are also significantly affected by host responses including public health services and measures to control occurrence of disease (Parham et al., 2015a). For example, vector-borne disease risk may be increasing as a result of climate change in some areas but kept at bay as a result of public health efforts (e.g. Europe) while in other regions, vector-borne disease transmission may be increasing both due to climate change and other factors that may include insufficient public health capacity to manage transmission (e.g. parts of West Africa). It is therefore crucial that adaptation planning occur to manage the changing risks posed by the effects of climate change on vector-borne diseases and that this planning take into consideration the impacts within the range of interacting socio-economic systems in which disease impacts will be felt (Parham et al., 2015b). As such, there is a need for approaches that can embrace this complexity and inform decision-making with evidence – both scientific and stakeholder informed experiences.

Evidence-based and evidence-informed approaches have been gaining increasing traction in public policy in contrast to ad-hoc, crisis-driven responses to

public health problems. These approaches recognize the importance of being systematic and transparent while making use of the best available evidence. Deliberative multi-criteria decision-aid (MCDA) is one such compatible approach that offers a framework for climate change adaptation and adaptation to vector-borne disease where the best available evidence and stakeholder-informed experiences can be combined in order to improve adaptation planning strategies.

This thesis aims not to make biological model predictions on occurrence of disease, but rather to identify and examine concerns of importance in adaptation planning and management of anticipated vector-borne disease risks under climate change.

THESIS OBJECTIVES AND FRAMEWORK

This thesis aims to contribute to climate change adaptation research via the development of an action-oriented, contextualizable approach for integrating important elements necessary for informed adaptation to vector-borne disease. Borrowing from a climate change vulnerability framework (Füssel, 2007a) where at least three important stages can be distinguished notably the *impact assessment phase,* the *vulnerability assessment phase,* and the *adaptation assessment phase,* this research has interpreted these phases in the context of vector-borne disease risk in order to study key decision concerns of importance in adapting to climate change. Two differing contexts are examined: the province of Quebec (Canada), where vector-borne diseases are present but not the primary burden of disease, and Burkina Faso (West Africa), where vector-borne diseases contribute to the primary burden of disease. With respect to three phases of interest, *Impact assessment* has been interpreted as pertaining to identifying which diseases are of concern under climate change, *Vulnerability assessment* has been interpreted as pertaining to assessing current readiness of a population to respond to a vector-borne disease and the *Adaptation assessment* phase has been interpreted as pertaining to assessing management options to reduce the impacts of a vector-borne disease under climate change. Toward this end, the main research objectives identified include:

Phase 1 - Impact assessment: To identify and compare key concerns in prioritizing vector-borne diseases in two different regions facing changing risks to vector-borne disease transmission as a result of climate change: the eastern province of Quebec (Canada) and the West African country of Burkina Faso. (Chapters 2 and 3)

Phase 2 - Vulnerability assessment: To describe and evaluate the current population preparedness of southern Quebec to a climate sensitive vector-borne disease using West Nile virus as the vector-borne disease of interest. (Chapter 4)

Phase 3 - Adaptation assessment: To develop management options to a climate sensitive vector-borne disease in southern Quebec (using West Nile virus as the disease of interest) and climate sensitive vector-borne disease in the contrasting region of Burkina Faso where malaria was used as the climate sensitive vector-borne disease of interest. (Chapters 5 and 6)

A cross-sectional approach was used to examine current knowledge and concerns of local stakeholders and populations residing in the two study regions of interest. The population of Quebec was used as the main study population in all three phases while case studies using the population of Burkina Faso were undertaken in phases 1 and 3. Data collection in Quebec took place at three separate time points: April and September 2014, and spring 2016 for phases 3, 1 and 2 respectively. Data collection in Burkina Faso took place in February 2015 for phases 1 and 3 respectively. West Nile virus, the disease of interest in Quebec in phases 2 and 3, has been in circulation in the province since 2002, with the highest incidence recorded to date in 2012 at 1.62 cases per 100,000 (Ouhoumanne, et al., 2014). Malaria, the disease of interest in Burkina Faso in phase 3, has an estimated incidence over 1 case per 1,000 population in this region (WHO, 2015a).

The research protocol for this thesis was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (CERES)) (certificate number 14-025-CERES-D). Additional ethical approval was obtained from the Comité d'éthique pour la recherche en santé in Burkina Faso (Deliberation number 2015-02-019) for the parts of the research project having taken place in that country.

CHAPTER 1: LITERATURE REVIEW

Climate change is one of the leading contributors of global environmental change with significant public health consequences anticipated now and over the next several decades (Costello et al., 2009). Climate change has been described as one of the most important health risks of the 21st century as a result of both direct and indirect predicted impacts on human health and supporting ecosystems (Costello et al., 2009; Frumkin et al., 2008; Watts et al., 2016; Whitmee et al., 2015; WHO, 2017b). Vector-borne diseases, a subset of infectious diseases that are transmitted primarily by arthropod vectors, have been identified as an important public health concern and are in addition susceptible to the effects of climate change (Smith et al., 2014; WHO, 2017a). While other communicable diseases have also been predicted to be affected by climate change, only vector-borne disease examples will be presented in this thesis. The first part of this chapter reviews current scientific knowledge on climate sensitive diseases with an emphasis on vector-borne diseases of interest in Quebec (Canada) and Burkina Faso (West Africa), and the challenges surrounding adaptation management of these diseases. The second and third parts of this chapter review climate change adaptation and compatible approaches to contribute to this research.

Vector-borne diseases and climate change

Vector-borne diseases (VBDs) are illnesses caused by pathogens such as viruses, bacteria or parasites and which are transmitted to humans by arthropods, including mosquitoes, ticks, and biting flies. Vector-borne diseases have a long history of transmission with humans. In the early 19th century,

malaria – one of the most notorious of the vector-borne diseases - had active transmission in nearly all countries (Hay et al., 2004; Mendis et al., 2009). However, following strong vector-control efforts undertaken in the 1950s and 60s, malaria transmission in particular, but also that of other vector-borne diseases, contracted and became primarily concentrated around tropical and sub-tropical regions of the world (Mendis et al., 2009). On a global scale, existing VBDs continue to contribute significantly to the global burden of disease – both in terms of morbidity and mortality - with nearly half of the world's population estimated to be infected with at least one VBD pathogen (Lemon and Institute of Medicine (U.S.) eds , 2008). Malaria alone is estimated to contribute to over 400,000 global deaths annually, with a majority of these deaths concentrated in the African Region (WHO, 2015b). Additionally, vector-borne diseases are an important threat in terms of emerging and re-emerging infectious diseases as their occurrence and distribution continues to be influenced by a number of ongoing global environmental changes.

Climate change is an ongoing process amidst a larger context of human induced social-environmental changes. These include changing population dynamics, landscape and land use change, lifestyle changes with implications for food consumption and agricultural practices as well as consumption of goods and the environmental impact of producing them all of which is occurring at an unprecedented scale and pace and affecting ecosystem dynamics and human health in the process (Costello et al., 2009; IPCC, 2014; Whitmee et al., 2015). These changing ecosystem dynamics and interactions with human socio-economic systems have important consequences for infectious disease dynamics as a result of altering the survival, rate of reproduction and contact frequency between species (Gubler, 2002; Parham et al., 2015a). Additionally, determinants of health such as the environmental characteristics of the location where individuals live, local physical infrastructures, social and institutional contexts and

demographic factors also affect an individual's underlying exposure and therefore sensitivity to infectious disease and ability to cope or respond (adaptive capacity) to transmission risk (IPCC, 2014). As a result of these effects of climate change on both natural and human systems, infectious disease risk and vector-borne disease risk in particular are anticipated to increase, with some observed changes having already taken place (Smith et al., 2014).

Climate change is likely to affect a number of infectious diseases by contributing to their 1) emergence, 2) re-emergence or 3) by causing shifts in their geographical or temporal distribution (Rose et al., 2001). A number of such observations have already been made including the emergence of the bluetongue virus in Europe (Purse et al., 2005), the re-emergence of malaria in the highlands of East Africa (Pascual et al., 2006) and changing distribution of Lyme disease in North America (Ogden et al., 2008, 2006). These diseases that are sensitive to changes in climate are sometimes referred to as "climate sensitive infectious diseases" (CSIDs) and include those communicable diseases, such as vector-borne, water-borne, food-borne, air-borne and rodent-borne diseases, that have a component of their transmission that is sensitive to direct changes in climate including changes in temperature, precipitation and related environmental variables (e.g. humidity, length of growing season). Infectious diseases with transmission cycles outside of the human body are more susceptible to changes in weather and climate (Haines et al., 2006). This thesis focuses on the subset of climate sensitive infectious diseases that are vector-borne with particular emphasis on West Nile virus and malaria. Malaria is known to be endemic in Burkina Faso (Kouyaté et al., 2007), and West Nile virus, has been circulating in the Canadian province of Quebec since 2002 (Public Health Agency of Canada, 2008). Both diseases are mosquito-borne (i.e. vector-borne).

From a simplified perspective, changes in weather and climate result in changing incidence of climate sensitive infectious diseases due to changes in the

rate of proliferation, survival and transmission of pathogens and their vectors (Gubler et al., 2001). The seasonal and spatial patterns of these agents may also change (Rose et al., 2001). Temperature and precipitation changes affect water cycle dynamics and in turn can have implications for ecosystems, microbial and parasitic evolution. For VBDs, changes to the water cycle or water cycle dynamics can affect the availability of breeding places for vector species. Heavy rainfall, flooding and drought conditions can increase breeding space for vector species such as mosquitoes (via pools of water left behind following flood and/or drought events) and have been linked to VBD outbreak events such as Rift Valley fever in parts of Africa (Linthicum et al., 2007). Drought has also been linked to amplification of Saint Louis encephalitis virus in Florida as dwindling water sources may increase the likelihood of multispecies contact at available water sources (Shaman et al., 2002). Changes to temperature can affect the reproduction rate, survival rate, susceptibility of vectors to pathogens and rate of contact of vectors with host species as well as the replication and survival of pathogens within vector species (Gubler et al., 2001). Additionally, the timing of spillover of WNV from avian reservoirs to human populations is driven by shifts in feeding behaviour of *Culex* spp. mosquitoes in response to bird migration, a well know climate mediated phenomenon (Kilpatrick et al., 2006b). Changes in incidence of Malaria have been observed in south America in correlation with the El Niño Southern Oscillation (ENSO) (Gagnon et al., 2002), and outbreaks of WNV and Saint Louis encephalitis have been linked with warmer than usual temperatures in parts of North America (Chen et al., 2013; Githeko et al., 2000; Monath and Tsai, 1987; Reisen et al., 2006; Ruiz et al., 2010; Soverow et al., 2009). A list of climate sensitive vector-borne diseases and their climate sensitive components is shown in Table I.

Table I. Climate sensitive vector-borne diseases and climate sensitive mechanisms

Vector	Disease examples	Climate variables	Effect of climate change and Climate sensitive components	References
Mosquitoes	Malaria, Rift Valley fever, WNV	Heavy rainfall, flooding and increased avg. temperatures	Increase in breeding space for vector species such as mosquitoes (via pools of water left behind following flood events) Increased temperatures also accelerate vector reproduction and pathogen proliferation within the vector	(Paz, 2015)
	Dengue, chikungunya virus, yellow fever, Zika	increased avg. temperatures	Accelerated vector reproduction and pathogen proliferation within vectors	(Patz et al., 2005)
	Saint Louis encephalitis, WNV	Drought conditions and increased avg. temperatures	Increased breeding space for vector species such as mosquitoes (via pools of water left behind following drought events) Reduced number of water sources provides an opportunity for increased encounters of various species at available water sources Increased temperatures also accelerate vector reproduction and pathogen proliferation within the vector	(Shaman et al., 2004, 2005)
	Lymphatic filariasis	Increased avg. temperatures	Acceleration of parasite development and vector range expansion	(Dhimal et al., 2015)
	WNV, Eastern equine encephalitis	Milder winters, warmer summers, cooler falls	Extended transmission season, increased overwinter survival, range expansion, more frequent opportunities for transmission	(Kulkarni et al., 2015)
Ticks	Lyme disease, tick-borne encephalitis, Tularemia	Changing precipitation patterns, increased humidity and avg. temperatures	Vector and pathogen range expansion;	(Leighton et al., 2012; Ogden et al., 2008)
Midges	Bluetongue	Milder winters, increased average temperatures	Increased virus persistence and vector range expansion	(Purse et al., 2005)
Biting flies (sandflies, blackflies, tsetse flies)	Leishmaniasis, Trypanosomiasis, Onchocerciasis, Bartonellosis, Loaiasis	Increased avg. temperatures, changing precipitation patterns	Acceleration of parasite development and synergistic interactions between reservoir and vector	(Dhimal et al., 2015; Hunter, 2003; Shirzadi et al., 2015)
Triatomines	Chagas disease	Increased avg. temperatures	Changes in vector (& disease) distribution and vector activity	(Schilman and Lazzari, 2004)
Fleas	Murine typhus, Plague	Increased avg. temperatures and precipitation	Increased vegetation affecting rodent and flea density	(Hunter, 2003; Xu et al., 2014)
Snails	Schistosomiasis	Increased avg. temperatures	Changes in vector and disease distribution	(Yang et al., 2005)

Climate change and vector-borne disease challenges

Due to the inherent sensitivity of arthropod vectors to weather and climate which affect vector habitat range, distribution and abundance (Martens et al., 1995), vector-borne diseases have been identified as likely candidates that will be affected by climate change. However, the link between climate change and vector-borne disease has been a topic of intense debate over the years owing to the numerous interacting drivers, especially non-climatic, that also affect vector-borne disease dynamics (Altizer et al., 2013; Campbell-Lendrum, D., 2015; Patz et al., 2005; Rogers and Randolph, 2000, 2006). Climate has likely played an important role on human health to date, but this has been highly mediated by the numerous interacting other stressors and drivers of disease risk which to date have been poorly quantified (Smith et al., 2014). These include, but are not limited to, increasing vector resistance to chemical vector-control interventions (Benelli, 2015; Trape et al., 2011), parasite resistance (in the case of malaria) to treatment (Bhatt et al., 2015; Trape, 2001), relative public health capacity (Hay et al., 2004), poverty (Curtis et al., 2003; Worrall, 2002), weakened immune systems as a result of co-occurring health risks (malnutrition, and other infections), globalization contributing to increased transport of vectors and pathogens to new regions (Benedict et al., 2007), human migration as a result of political conflict (Githeko et al., 2000) and lifestyle changes that are driving environmental exposure to vectors and pathogens (Confalonieri et al., 2007; Mills et al., 2010).

As a result of the debate, much effort to date has been focused on attributing past changes in disease to climate change (Campbell-Lendrum, D., 2015; Patz et al., 2005; Rogers and Randolph, 2006). The effect of climate on disease vectors is well recognized; however the timing and magnitude of anticipated changes is controversial owing to the aforementioned additional non-climatic drivers of disease risk (Smith et al., 2014). Climate warming is likely to increase disease risk in areas currently limited by lower temperatures; however,

the nature of public health measures in place in these locations are likely to significantly modify the impacts of these changes.

The challenge in attributing climate change to changes in vector-borne disease incidence lies in clearly linking the effect of climate change on elements which affect the basic reproduction number of a disease and disentangling this effect from the numerous confounders which can also affect these parameters (Rogers and Randolph, 2006). Doing so requires extensive data over time which in many cases is simply not yet available at a level of detail that would allow confident predictions (Rogers and Randolph, 2006). Several studies have sought to make predictions on the effects of climate change on diseases including malaria (Martens et al., 1999; Pascual et al., 2006; Rogers and Randolph, 2000) and dengue (Hales et al., 2002; Martens et al., 1997). These predictions have not been met without controversy given the often-conflicting results of the models with some models predicting areas of disease emergence (Martens et al., 1999, 1997) and others predicting areas of disease contraction (Rogers and Randolph, 2000). These results have differed greatly due to the nature of the models themselves (e.g. biological (Martens et al., 1999, 1997) versus statistical (Rogers and Randolph, 2000)) and the assumptions made in the construction of the models.

The many processes that drive disease dynamics are complex in and of themselves and even more difficult to model together in a comprehensive model. Furthermore, some argue that the link between climate and diseases such as malaria have become less strong and are now outweighed by economic and public health capacity (Gething et al., 2010). The exact change in distribution that malaria and other vector-borne diseases will exhibit as a result of climate change remains unclear, with some areas likely to experience decline as a result of temperatures exceeding the vector or pathogen`s tolerance levels while other areas will likely experience emergence as a result of temperatures favouring

transmission. Changes in seasonality and length of the transmission season are expected as has been suggested by WNV models (Morin and Comrie, 2013). The health impacts of emerging and re-emerging vector-borne disease will inevitably depend on localized factors and the interacting effects of climate and socio-economic conditions.

From a public health perspective, CSIDs are complex diseases to study and plan for as they arise at the interface of multiple interconnected systems and scales – human, environmental, animal - and our technical and societal adaptations to these changes are challenging (Charron et al., 2004). Socio-economic factors and resulting behavioural changes as well as other forces have been shown to play an important role in the emergence of CSIDs as observed recently in California with increases in WNV following foreclosures of homes and resulting abandoned swimming pools (Reisen et al., 2009). Warmer weather has been identified as a likely motivator for people to spend more time in the sun and as such is likely to increase the risk of skin cancers if cloud cover remains the same (Thomas et al., 2012; Williamson et al., 2014). Warmer weather in traditionally colder climatic regions and the likely resulting behavioural change of people spending more time outdoors may also increase the chances of contact with mosquitoes thereby increasing the risk of VBD transmission. Additionally, driving forces such as global ecosystem change, the existence of suitable climate, the geopolitical stability of a region, the economic stability and related nutritional status and general health of a population, state of the underlying health infrastructure, the immunity of the local population, the existence of suitable vectors and reservoir hosts, changes in human behavior and other factors are crucial components that all need to be taken into account when planning public health strategies (Rose et al., 2001; WHO, 2012).

Climate sensitive vector-borne diseases in Canada

A recent review of emerging vector-borne diseases of concern in Canada identified Lyme disease and West Nile virus as priority pathogens of interest (Kulkarni et al., 2015). Lyme disease is a tick-borne disease caused by bacteria (*Borrelia burgdorferi)* and transmitted in Canada primarily by *Ixodes scapularis* (*Ixodes pacificus* in western Canada) while West Nile virus is a mosquito-borne virus transmitted by infected mosquitoes primarily of the *Culex* genus. Both diseases are currently present in Canada and their expansion (Ogden et al., 2008; Ogden, 2013) and epidemic cycles have been linked to climatic drivers (Chen et al., 2013). These same vector species of ticks and mosquitoes are also known to be vectors of other diseases. For example, *Ixodes scapularis* is also known to be a vector of other tick-borne pathogens including *Anaplasma phagocytophilum, Babesia microti, Borrelia miyamotoi,* and Powassan virus (Bakken and Dumler, 2008; Diuk-Wasser et al., 2014; Ogden et al., 2014; Thompson et al., 2001), while *Culex* mosquitoes can also carry St. Louis encephalitis and Western equine encephalitis. Additionally, other mosquito and tick-borne diseases, with historical transmission or for which vectors and suitable transmission conditions exist, are of interest to monitor in Canada as climate induced changes to the vectors or transmission conditions for these diseases may result in altered risk under climate change (Table II).

Lyme disease has been receiving increasing public and political interest in Canada as demonstrated by the recent adoption of a Federal Framework on Lyme Disease aimed at ensuring government surveillance, and management guidelines for this disease (Government of Canada, 2017) and has also been the subject of a number of recent studies (Aenishaenslin, 2015; Bouchard, 2013; Leighton et al., 2012; Ogden, 2009). While West Nile virus received much initial attention following its emergence in Canada (Bouden et al., 2008; Buck et al.; Drebot et al., 2003; Elmieh, 2009; Ludwig et al., 2002), it continues to be a disease of interest in

Canada as outbreak risks remain high under varying climatic conditions (Chen et al., 2013). This thesis focuses on WNV for the Canadian aspects of the research.

Table II. Potential climate sensitive disease threats in Canada and Africa

Vector	Disease	References
Canada		
Mosquitoes	**West Nile virus, St-Louis encephalitis, Eastern Equine encephalitis, Western Equine encephalitis, Jamestown Canyon virus, Cache Valley virus, Snowshoe Hare virus, malaria,** *Japanese encephalitis, dengue, Zika, Chikungunya virus*	(Githeko et al., 2000; Kulkarni et al., 2015)
Ticks	**Lyme,** human granulocytic anaplamosis, human babesiosis, Powassan encephalitis, Ehrlichiosis, **Rocky Mountain spotted fever,** tularemia, relapsing fever, Colorado tick fever,	
Midges	*Bluetongue*	
Fleas	**Murine typhus, Plague**	
Africa		
Mosquitoes	**Malaria, dengue, yellow fever, Chikungunya virus, West Nile virus, Rift Valley fever, Zika, lymphatic filariasis**	(Chevalier et al., 2016 ; Githeko et al., 2000 ; Kovats et al., 2001)
Ticks	**Crimean Congo haemorrhagic fever, Human relapsing fever**	
Biting flies	**Leishmaniasis, Trypanosomiasis, Onchocerciasis, Bartonellosis, Loaiasis**	
Snails	**Schistosomiasis**	

Bold – endemic or historic transmission

West Nile virus

Etiology and transmission

West Nile virus (WNV) is a single-stranded RNA virus of the *Flavivirus* genus that was first isolated in Uganda in 1937 (Petersen and Marfin, 2002; Smithburn et al., 1940). The disease is transmitted in nature to humans by the bite of infected female mosquitoes, primarily of the *Culex* genus in North America, with *Culex pipiens* and *Culex restuans* prime vectors in the Northeast and *Culex tarsalis* in the West and other *Culex* species implicated in Central and South America (Turell et al., 2005). WNV transmission can also occur through

blood and organ donations (Granwehr et al., 2004). WNV is maintained in an avian host reservoir, of which the American Robin (*Turdus migratorius*) has been one of the main implicated species, though birds from many other families have also been shown to be competent amplifying hosts (Kilpatrick et al., 2006a, 2007; Ladeau et al., 2008). Incidental infections occur in humans and other dead-end hosts such as horses (infections that do not contribute to maintaining the disease transmission cycle) (Artsob et al., 2006).

Diagnosis, Symptoms and Treatment

Diseases of the *Flavivirus* genus are known to cause considerable disease in humans, often neuroinvasive in nature, and include dengue, yellow fever, Japanese encephalitis and tick-borne encephalitis (Burke and Monath, 2001). Incubation of WNV varies from 3-14 days and diagnosis can generally be confirmed by testing of serum or cerebrospinal fluid for IgM antibodies to WNV though cross-reactivity can occur with related flaviviruses (Petersen and Marfin, 2002). Symptoms of WNV vary with a majority of infections asymptomatic in nature while approximately 20% of infections present with febrile illness and general muscle weakness (Petersen LR et al., 2013). In rare cases, WNV presents with severe neurologic symptoms and death (<1% of infections) (Petersen LR et al., 2013). The North American strain has shown all ages groups to be susceptible to WNV, though older adults and those with compromised immune symptoms appear at higher risk for neuroinvasive forms of infections (Hayes et al., 2005). No specific treatment exists at this time and supportive care is the main course of action for hospitalized cases (Petersen and Marfin, 2002). WNV has been a notifiable disease in Canada since 2003.

Prevention and Control

Given the lack of effective medical counter measures for WNV, disease prevention and control efforts have been heavily oriented at disease avoidance

via vector-targeted, and human-targeted measures. Vector-level interventions for WNV have primarily included the use of larvicides – targeting immature mosquitoes in their aquatic stages before they develop into adult mosquitoes - and habitat modification measures to reduce vector breeding sites and vector density either through the removal of containers breeding sites or larger scale measures such as the draining of marshes (Hayes et al., 2005; Hayes and Gubler, 2006; Nasci et al., 2013; Reisen and Brault, 2007). In some regions, adulticiding – the targeting of mature mosquitoes with aerosolized chemicals – has also been employed (Carney et al., 2008). Human-level interventions are also part of prevention and control efforts and include the adoption of preventive measures such as mosquito repellents containing DEET or wearing of protective clothing to reduce the risk of mosquito bites (Bellini et al., 2014; Public Health Agency of Canada, 2015). Mosquito surveillance and disease education are also important components of these prevention and control efforts.

Historical distribution and emergence in North America

A number of outbreaks of WNV of increasing frequency and severity have occurred over the years in countries of the Middle East such as Egypt (1950s) and Israel (1957) but also in France (1962-63), South Africa (1974) and Romania (1996) (Sejvar, 2003). WNV is now known to be endemic in Africa, the Middle East, Asia, southern Europe and North America (Zeller and Schuffenecker, 2004). WNV made its appearance in North America following an outbreak in New York City in the summer of 1999 (Lanciotti et al., 1999; Nash et al., 2001). Following this outbreak, West Nile virus subsequently spread southward, westward and northward across North America and into Central and South America and into Canada in 2001 (Campbell et al., 2002; Venter, 2001). While the New York strain of WNV has been genetically linked to a strain that occurred in Israel in 1998 (Lanciotti et al., 1999), it is not clear how the virus was introduced into North America. Since its introduction, WNV has mutated with the new genotype having

displaced the previous genotype (Davis et al., 2005; Kramer et al., 2008). This new genotype, WN02, is believed to have become more virulent and easily transmissible by *Culex* spp. mosquitoes (Kramer et al., 2008; Moudy et al., 2007). Over 46,000 cases of neuroinvasive and non-neuroinvasive WNV combined were reported in the US since 1999 (CDC, 2015, 2017) and over 5,400 cases of WNV reported in Canada since 2002 (Government of Canada, 2015, 2016). These numbers are likely an underestimation of the true burden of WNV given the primarily asymptomatic nature of the disease.

Effect of Climate change on WNV

Culex mosquitoes, the primary vectors of West Nile virus, are multivoltine meaning that they produce multiple generations in a year (Wood et al., 1979). Establishing clear links between observed climate change to date with recorded changes in WNV incidence rates has been challenging as a result of the many ecological drivers that vary by species and region in response to different climatic drivers (Hongoh et al., 2009). Nevertheless, important WNV outbreak events in Canada have been linked to unseasonably warm and unusual climatic conditions. For instance, in the province of Quebec, the 2002 emergence of WNV was linked to above seasonal winter and summer temperatures preceding WNV's emergence (El Adlouni et al., 2007) while in the Canadian prairie provinces (Manitoba, Saskatchewan and Alberta), the major 2007 outbreak of WNV that caused over 2000 infections alone, was linked to warm winter and warm and wet spring conditions preceding the outbreak (Chen et al., 2013). Extrapolating from observed trends of climate change on winter and summer temperatures, climate change has been predicted to further affect WNV as a result of increasingly milder winters and longer, hotter summers favoring more generations of mosquitoes per year (Epstein, 2001). A longer mosquito season increases enzootic amplification with greater chances of subsequent spill-over into human hosts later in the season (Hongoh et al., 2009).

Climate sensitive vector-borne diseases in Africa

The African region bears the double burden of having least contributed to climate change and yet is predicted (and has already been observed) as likely to suffer some of the most severe impacts (Patz et al., 2007). The west African region in particular, which is already severely affected by numerous health challenges including malnutrition, poverty and other infectious diseases, is likely to continue to experience food security challenges as a result of increased drought and desertification in the region (Niang et al., 2014). Due to climatic conditions in Africa, a large number of vector-borne diseases have thrived in this region. The most recent Intergovernmental Panel on Climate Change (IPCC) report (AR5) chapter on Africa cites malaria, leishmaniasis, Rift Valley fever and other tick-borne diseases as vector-borne diseases of concern under climate change (Table II) (Niang et al., 2014). This thesis addresses malaria as one of the most important causes of morbidity and mortality in the African region. Clearly linking climate signals to changes in disease rates is particularly challenging in this context as a result of insufficient health capacity and other synergistic factors including poverty. Some consensus has been reached showing that recent increases in malaria incidence in four high-altitude sites in East Africa was linked to corresponding increases in temperature in these same sites since the 1950s (Pascual et al., 2006).

Malaria

Etiology, Transmission, Symptoms and treatment

Malaria is a parasitic disease caused by *Plasmodium* protozoans and transmitted by the bite of infected mosquitoes of the *Anopheles* genus. Infection in humans is caused by a number of *Plasmodium* species including: *P. falciparum, P. vivax, P. ovale,* and *P. malariae* of which *P. falciparum* is the most common and considered the most severe (Pasvol, 2005a; Snow and Omumbo, 2006). Malaria is

maintained in a human-mosquito-human cycle. Symptoms can include flu-like symptoms, headache, fever, shivering but severe cases can also result in respiratory or neurological symptoms and death (Pasvol, 2005b). Other effects of malaria include anemia contributing to malnutrition, reduced birthweight and increased susceptibility to infection (Snow and Omumbo, 2006). In regions where malaria infection is widespread such as Sub-Saharan Africa, functional immunity can occur, though those with underdeveloped immunity (e.g. children) remain highly vulnerable (Snow and Omumbo, 2006). WHO recommended treatment is confirmatory testing by rapid diagnostic test (RDT) followed by artemisinin-based combination therapy (ACT) (WHO, 2016a). Late and inappropriate treatment of malaria can result in severe complications including death (McCombie, 1996).

Prevention and Control

Considerable effort and funding have been allocated to developing a malaria vaccine (Schwartz et al., 2012) and while progress has been made with a pilot trial of a candidate vaccine underway in Sub-Saharan Africa, a commercial vaccine is as of yet unavailable (WHO, 2016b). As a result, vector- and human-level interventions are employed to reduce the risk of malaria infection. WHO recommended vector-targeted strategies include the use of long-lasting insecticide-treated nets (LLIN) – where bed nets are coated with long lasting adult mosquito targeted chemicals and used to cover human sleeping areas - and indoor residual spraying (IRS) – where the interior of homes are sprayed with adult-targeted insecticides. Larval source management strategies (LSM) – targeting the immature mosquitoes in their aquatic stages – are also employed in some regions. LLINs also act as a human-level intervention protecting from immediate mosquito bites. Intermittent treatment of vulnerable groups with anti-malarial medication to reduce the risk to pregnant women and children is also recommended by the WHO (WHO, 2015c).

Malaria burden in Burkina Faso

While historical transmission of malaria was widespread (Hay et al., 2004) and extended to countries in Europe and Canada (Berrang-Ford et al., 2009), the current malaria burden is primarily concentrated in tropical regions and disproportionately affects poorer countries and the region of Africa in particular where the majority of deaths occur (Hay et al., 2004; WHO, 2016a). Malaria transmission is holoendemic in Burkina Faso and also among the leading causes of death. While progress has been made in reducing the malaria burden globally (WHO, 2016a), an estimated 40,000 cases still occur annually in Burkina Faso, a majority of them in children under 5 years of age (Murray et al., 2012b). As a comparison, globally 212 million cases and over 400,000 deaths were reported in 2015 (WHO, 2016a). Seasonal variation occurs in malaria transmission in Burkina Faso with the highest incidence occurring during the rainy season.

Effect of climate change on malaria

Both the *Anopheles* mosquito vector and *plasmodium* parasite are highly sensitive to temperature and to a lesser extent rainfall changes as the mosquito vector is dependent on surface water to lay its eggs. Optimal temperature ranges for the *Anopheles* mosquito is 25-30˚C with development shut down below 16˚C and malaria sporogony (i.e. parasite replication in the mosquito) slowed above 35˚C (Snow and Omumbo, 2006). As a result of these sensitivities, malaria distribution and incidence are expected to vary and have already been observed to have changed in the East African highlands as a result of climate change (Niang et al., 2014; Pascual et al., 2006). Multiple modelling efforts (Caminade, 2014; van Lieshout et al., 2004; Martens et al., 1999, 1997; Rogers and Randolph, 2000; Tanser et al., 2003) have been undertaken to assess the future risk of malaria under climate change but with divergent predictions as a result of different modeling approaches and the challenges of incorporating all important disease transmission factors. Nevertheless, further transmission changes in malaria are

expected and will vary by region with the largest effects predicted to be concentrated at the edges of malaria`s current distribution. Contraction will likely occur as a result of the vector and parasite temperature tolerances being exceeded and expansion is also anticipated as a result of temperatures increasing into optimal ranges for both the vector and parasite in other regions where they are currently limited by lower temperatures.

Climate Change adaptation to vector-borne diseases

Given current carbon dioxide (CO_2) emissions in the atmosphere over 400 parts per million and the threat of global warming passing the 2°C threshold – a threshold beyond which significant global ecosystem declines are projected – anticipatory adaptation is seen as an optimal and necessary response to projected changes in order to reduce the worst effects of climate change (de Bruin et al., 2009; IPCC, 2007a, 2014; Smith et al., 2009). Adaptation does not preclude ongoing parallel work on mitigation. Since the fourth assessment report, a very large body of literature has emerged on adaptation and vulnerability with an estimated doubling rate of this literature of less than 5 years (Burkett et al., 2014). Adaptation was defined in the IPCC fourth assessment report as adjustments to natural and human made systems in response to actual or expected effects of climate change and climate variability intended to moderate harmful effects or exploit beneficial opportunities (Confalonieri et al., 2007). In the fifth assessment, this definition has been expanded to distinguish between *incremental adaptation* – that aims to maintain the current functioning of systems or processes – versus *transformational adaptation* – that incorporates significant changes to a system to where it may no longer have the same functioning that it once had (Smith et al., 2014). Predicted impacts of climate change on health will vary widely by region (Costello et al., 2009) and health adaptation needs will depend on a variety of factors including the existing burden

of disease in these regions (Ebi et al., 2006; Smith et al., 2014). To date, much effort has been focused on quantifying climate change and its consequences, and assessing vulnerability of humans and systems to climate change (IPCC, 2007b, 2014), but adaptation action itself has been limited (Berrang-Ford et al., 2011) in part due to our limited understanding of the many remaining unknowns and synergistic effects between systems, but also lack of action-oriented approaches for assessing adaptation-relevant factors. This is beginning to change as research is being generated and priorities align towards building resilient systems (Ouranos, 2015). Climate change adaptation research is aimed at informing the development of policies to reduce the risks associated with climate change (Füssel and Klein, 2006). In order to inform the adaptation process, research is needed on what to adapt to and how to adapt. In a context of vector-borne disease, this requires information on 1) which diseases to adapt to, 2) understanding who is vulnerable and at risk, and 3) assessing management strategies to cope with these diseases, all of which are in line with recent World Health Assembly Resolutions on climate change and health (Campbell-Lendrum, D., 2015).

A Vulnerability assessment approach to vector-borne disease adaptation

A number of models have been proposed from various disciplines to help inform the adaptation research process including the risk-hazard framework, the social constructivist framework and the integrated vulnerability framework the later of which is described in the IPCC third and fourth assessment reports and guided the research here (Confalonieri et al., 2007). In Füssel & Klein`s (2006) review of vulnerability assessments to climate change, three important stages are described: The *Impact assessment* stage, the *Vulnerability assessment* stage and the *Adaptation assessment* stage. Whereas the *Impact assessment* stage is

concerned with understanding and identifying the effects of climate change such as the biophysical impacts of climate change, the *Vulnerability assessment* stage is concerned with understanding who is most vulnerable and at risk given anticipated socio-economic impacts and feasible adaptation (Füssel and Klein, 2006). Finally, the *Adaptation assessment* is concerned with identifying appropriate management strategies given anticipated effects and vulnerability to climate change. In a context of vector-borne disease adaptation, these three stages can be reframed as: 1) what diseases are we concerned about? 2) who is most vulnerable and at risk to these diseases? and 3) what are recommended measures to adapt to these diseases? And is the approach that has been employed here to guide and frame our research for informing the adaptation process.

VBD Impact assessment: what diseases are of concern?

Given the significant contribution of VBDs to the global burden of disease, further anticipated changes under climate change have solicited much public health concern (Campbell-Lendrum, D., 2015; Lozano et al., 2012; Murray et al., 2012a; WHO, 2008). While debate continues over climate signal attribution to changes in disease rates, methods are needed to help assess existing evidence and target priority diseases for adaptive action. A number of vector-borne diseases have been highlighted as being of interest under climate change (Campbell-Lendrum, D., 2015; Medlock and Leach, 2015; Semenza and Menne, 2009; Sutherst, 2004), but deciding which diseases to prioritize remains an important challenge in many regions. A number of disease prioritization studies have taken place over the years in various countries and under various health contexts (Balabanova et al., 2011; Brookes et al., 2014a, 2014b; Capek, 2010; Cardoen et al., 2009; Cox et al., 2013, 2013, Doherty, 2000, 2006; Gilsdorf and Krause, 2011; Havelaar et al., 2010; Institut de Veille Sanitaire, 2002, 2010, Krause, 2008a, 2008b; Ng and Sargeant, 2012a). Disease prioritization exercises

aim to structure reflection and guide decisions in order to improve effectiveness of resource allocation and efforts (Rushdy and O'Mahony, 1998). While multiple methods have been employed to conduct disease prioritization from disease scoring and ranking and deliberation by experts, the need for a systematic and transparent process is often called for to help increase acceptability and clarify resulting priorities. A recent editorial in the Lancet criticized the lack of publicly available information on the prioritization process used following the released list of antibiotic research priorities by the WHO (The Lancet Infectious Diseases, 2017) and highlights the need for transparent processes. Multicriteria decision aid processes have been used to a limited extent in disease prioritization and are of interest as they offer a systematic and transparent approach to setting priorities.

VBD Vulnerability assessment: assessing population preparedness to VBDs

In order to improve proactive planned public health adaptation, it is important to assess the current knowledge and awareness of the general public to CSIDs. Furthermore, as adaptation and vulnerability are inextricably linked, it is important to assess the potential adaptive capacity of a population in order to improve adaptation planning where this capacity is low. Socio-economic factors are generally used as the prime indicators of adaptive capacity, however, taking into account socio-cognitive factors is thought to provide a more accurate reflection of what behaviours individuals will actually adopt (Grothmann and Patt, 2005).

A number of social cognitive models have been developed to help predict human behaviour specifically as pertains to health behaviour including the health belief model (HBM) (Rosenstock, 1974) with additions by Bandura (1977), the theory of reasoned action (Ajzen and Fishbein, 1980), the theory of planned behaviour (Ajzen, 1991), and the prevention motivation theory (Rogers, 1983)

among others. These models measure similar dimensions of cognitive reasoning as pertains to health behaviour, including perceived severity, susceptibility, barriers, benefits and self-efficacy the underlying premise of which is that intention to undertake an action arises from the interplay between knowledge, motivation, perceived susceptibility, capability and effectiveness (Few, 2012). Grothmann and Patt (2005) developed a model based on prevention motivation theory that specifically incorporates adaptive capacity in order to help understand human motivation and barriers around climate change adaptation. With regards to CSID adaptation, as Few (2012) argues, it may be premature to advocate for one specific health model at this time, but the model developed by Grothmann and Patt (2005) may provide a helpful framework to analyse disease risk behaviour adaptation.

VBD adaptation assessment: Managing existing and anticipated changes to VBDs

In assessing adaptation options around vector-borne disease management, a number of pieces of key research are needed to inform the decision process. This includes current transmission distribution and burden, models of anticipated disease spread under climate change, available and anticipated management strategies and their evaluated efficacy. Additionally, in an adaptation context, the relevant sectors likely to be affected by adaptation options under consideration should be included in adaptation processes.

To make an informed decision, the best available evidence and information should be used to inform the planning and eventual decision process. Inspired by a recent Lyme disease (LD) model constructed to examine management strategies for LD in the province of Quebec (Aenishaenslin et al., 2013), a multi-criteria decision aid approach is used here to examine decision concerns and management options for adaptation to WNV in Quebec and malaria

in Burkina Faso. Given the similarities in nature of vector-borne diseases in terms of management concerns and categories of management strategies, the Lyme disease model offers a useful starting point in planning management strategies for other vector-borne diseases.

Assessing options for adaptation needs to go beyond criteria of cost-effectiveness of interventions alone. Criteria included should be complete, operational (comparable) mutually independent and non-redundant (de Bruin et al., 2009). Füssel (2006) suggests the following criteria be considered in assessing adaptation options: social determinants of vulnerability, current vulnerability to climate variability addressed, compatibility with existing policy goals, feasibility, and estimated burden of disease avoided. Social determinants of vulnerability are similar to social determinants of health, but will vary depending on the specific health outcome being examined. Other criteria that have been considered in other adaptation contexts can be helpful. In their study in the Netherlands, de Bruin and colleagues (2009) used the following criteria: the importance of option in terms of expected gross benefits that can be obtained, the urgency of the option, the no-regret characteristics of the option (good to do irrespective of CC), the co-benefits to other sectors and domains, the effect on climate mitigation (e.g. land use changes that reduce emissions as side effect) and in a separate evaluation, the 3-part feasibility of an option, scored their technical, societal and institutional complexity. The use of a multi-criteria decision aid approach allows for the systematic evaluation of options over multiple criteria simultaneously and allows both participating stakeholders and decision-makers to consider other dimensions of concern in assessing management strategies to a vector-borne disease. Additionally, the use of a multi-criteria decision aid approach in a deliberative, multi-stakeholder setting allows the inclusion of relevant stakeholders to voice issues of concern related to management of the disease of interest.

Evidence-Informed Public Health

The concepts of evidence-informed public health (EIPH) and evidence-based public health (EBPH) have arisen over the years in an attempt to improve the quality, robustness and likelihood of success of public health decisions and policy by putting together the best available research and knowledge of the most "effective" approaches in order to improve the problem at hand (Brownson et al., 2009; Jenicek, 1997; Kohatsu et al., 2004). Inspired in part by evidenced-based medicine (EBM) - which intended to formalize a more systematic approach to medical practice by emphasizing the latest clinical research over intuition (Guyatt et al., 1992), - evidence-informed approaches take root in epidemiology to provide the best available scientific-evidence (Jenicek, 1997) and have evolved in some instances to integrate community preferences for the improvement of population health (Kohatsu et al., 2004).

Evidence-informed public health (EIPH) is defined by the National Collaborating Centre for Methods and Tools (NCCMT) as "the process of distilling and disseminating the best available evidence from research, context and experience, and using that evidence to inform and improve public health practice and policy". The broad goal of evidence-informed and evidence-based public health is to improve the health of populations using best available evidence (Public Health Agency of Canada, 2014). A number of steps are defined as key to informing this process including appraising the evidence, adapting it to the local context, implementing it, and evaluating its effectiveness (Ciliska et al., 2008).

This "evidence-informed" approach to health practice, decision-making and policy setting is not unique to the health sector and has evolved over the last several decades as a response, in part, to crisis-driven, experimental, ad-hoc policy setting, and involves the cross-mixing of research and politics where potentially contentious viewpoints may be involved (Baltussen and Niessen,

2006; Kohatsu et al., 2004; Pawson, 2002). However, evidence-based decision-making is not a ubiquitous approach to policy setting. Fafard (Fafard, P., 2008) points out that “evidence is not always used or even sought out” in the policy making process nor is it always used to “guide the decision-making but rather to justify it” (p.11). Fafard (Fafard, P., 2008) also points out that “different kinds of evidence are used in different kinds of ways” in the policy setting process.

Numerous methods are available to gather evidence for use in evidence-informed approaches including systematic reviews, realist reviews, economic evaluations, meta-syntheses, and deliberative processes. Whereas systematic reviews are comprehensive syntheses of existing research that aim to produce overviews of ‘what works’, the realist review takes this effort a step further in trying to elucidate what works for whom and in what context (Pawson, 2002). Economic evaluation aims to maximize economic efficiency and there are many methods that have been developed over the years to do this (Rozworski, 2014). Meta-syntheses aim to make more accessible the results from qualitative studies with an interpretation of findings that contributes to elucidating the underlying concepts and building new theories (Finfgeld, 2003). Deliberative processes are likely among the most distinct of the methods mentioned as they typically involve group discussion of the reasons for and against different courses of action (Gauvin, 2011). According to Abelson (2003), deliberative processes have arisen from different schools of thought: deliberative democracy - seeking to engage marginalized and minority groups in planning that incorporates collective judgement - and knowledge translation, where exchange and dissemination of knowledge is sought to improve the health of populations (Abelson et al., 2003; Gauvin, 2009).

The concept of public health has broadened beyond simply the actions taken by public health officials to protect the health of populations to include what societies do collectively to assure health conditions for all (Institute of

Medicine, 2003; Kohatsu et al., 2004). This expanded view places individuals and communities as active participants in the process of ensuring public health (Institute of Medicine, 2003; Kohatsu et al., 2004), and adds support to the use of deliberative processes in public health in order to add a level of ownership and responsibility to the collective action required to ensure population health.

Given the broad effects on society that climate change is predicted to have, active participation of communities along with the best available scientific evidence will be crucial in the search for robust adaptation strategies in order to adapt potential strategies to existing contexts and ensure acceptability and appropriation of proposed adaptation responses by local residents.

Deliberative MCDA as an EIPH approach

Multi-criteria decision aid (MCDA) (also known as multi-criteria decision analysis, multi-criteria decision-making or multi-criteria evaluation) is a decision support framework that has its origins in the fields of mathematics and operations research and has been used in a wide number of disciplines ranging from environmental management (Gilliams et al., 2005; Kiker et al., 2005), strategic management, agriculture (Fealy et al., 2010), transportation (Macharis et al., 2012) and urban planning (Ellis et al., 2004; Papazoglou et al., 2000), and to a limited but growing extent in public health (Baltussen et al., 2010; Baltussen and Niessen, 2006). One of its many strengths lies in the ability to evaluate options beyond cost-benefit or cost-effectiveness analysis alone by integrating multiple types of evaluations, measured in their own units. At its core, MCDA offers a systematic and transparent process to evaluate decision alternatives over a set of explicitly defined criteria. MCDA assists in the structuring and reflection of the decision problem by highlighting strengths and weaknesses in the alternatives under consideration. When used in a 'deliberative' (Proctor and Drechsler, 2006), 'multi-stakeholder' setting (sometimes referred to as multi-

actor (Macharis et al., 2012), social (Munda, 2004), participatory or simply stakeholder MCDA (Banville et al., 1998)), MCDA can provide further transparency to the process by facilitating the identification of similarities and differences in stakeholders' viewpoints (Macharis et al., 2012). The end result is a richly-documented process that can inform decision-making.

Large scale complex problems which lie at the intersection between natural and human systems have need for approaches capable of integrating diverse viewpoints, including the broader public, which Funtowicz and Ravetz called an extended community of peers (Funtowicz and Ravetz, 1991, 2003; Garmendia et al., 2010). The deliberative MCDA framework combines mathematical methods with participatory approaches to address complex and uncertain problems (Munda, 2004) borrowing from Post-Normal Science (Funtowicz and Ravetz, 2003), Complex Systems Theory and social constructivism (Berger and Luckmann, 1966). Post-normal science evolved out of the field of Ecological Economics in contrast to reductionist science and aims to integrate elements of uncertainty, value loading and the existence of multiple legitimate perspectives into a coherent framework in order to address global environmental issues (Funtowicz and Ravetz, 2003). Complex systems theory acknowledges the existence of multiple, diverse components interacting in nonlinear fashions with feedbacks between them, able to self-organize and emit emergent properties (Funtowicz and Ravetz, 1994). A system is complex if it cannot be fully described from a single perspective, nor described as the sum of the characteristics of the individual components alone (Funtowicz and Ravetz, 1994). Social constructivism posits that knowledge is socially constructed via interaction and learning among individuals (Berger and Luckmann, 1966). These underpinnings are coherent with a deliberative MCDA framework where the results depend on the structuring of the problem, which in turn is shaped by those involved in defining the problem, i.e. the stakeholders. Stakeholders are defined by Banville (1998) as anyone with

a vested interest in a problem who 1) affects it, 2) is affected by it or 3) both affects and is affected by it and expanded by Munda (2004) to include social actors in a broader sense beyond organized groups alone. The validity of the MCDA process rests not in the existence of some objective 'truth', but rather in the representative capturing of the problem including the stakeholders involved, the transparency offered by defining explicit criteria and expressing explicit value judgements on these to capture stakeholder perspectives on the decision problem in order to find not the best technical solution, but rather the best social and technical compromise solution among evaluated options (Munda, 2004).

The deliberative MCDA process offers an EIPH compatible approach to Public Health policy and decision-making that can incorporate the best available scientific evidence with community input and participation. At its broadest level, public health is concerned with the prevention and control of disease through a range of activities (Porta, 2008) including surveillance and policy making for the promotion of healthy behaviours, healthy communities and healthy environments. These broad objectives of public health can be loosely categorized into risk assessment (e.g. surveillance, drug evaluation, etc.) and risk management (e.g. policymaking, priority setting, etc.) types of activities. A number of frameworks have been proposed for the evaluation of health risks where the common elements include defining the health problem in its (broad) context, analyzing the risks associated with the problem, examining the options for addressing the risks, making decisions about which options to implement, applying the selected options and evaluating the results all within a process that allows for step iteration and involvement of stakeholders.

Although MCDA is a relatively new concept to public health, the literature has been steadily increasing in recent years. Many studies from the field of environmental management that have made use of MCDA have had public health implications (e.g.: healthcare site selection (Vahidnia et al., 2009), waste

management (Bellehumeur et al., 1997; Higgs, 2006; Seager et al., 2007) and various forms of toxic site selection (Brent et al., 2007; Khadam and Kaluarachchi, 2003), flood management and risk assessment (Bana e Costa et al., 2004; Levy, 2005; Pruyt and Wijnmalen, 2010)). The early public health related papers that have made use of MCDA have generally done so from an operational perspective, and rarely in a deliberative approach (Baltussen et al., 2010; Baltussen and Niessen, 2006; Lobo and Lins, 2010; Mt-Isa et al., 2011; Peacock et al., 2009; Ruzante et al., 2010) although it has been proposed (Baltussen, 2016). The decision type problems in public health that have broached MCDA range from risk assessments of various kinds such as health technology assessments (Husereau et al., 2010; Tony et al., 2011), drug assessments (Nutt et al., 2010), pathogen assessments (Cox et al., 2013; Ng and Sargeant, 2012b, 2012a; Ruzante et al., 2010), treatment alternatives), policy making and priority setting (Baltussen et al., 2007; Bots and Hulshof, 2000; Defechereux, 2012; Jehu-Appiah et al., 2008; Wenstøp and Magnus, 2001; Youngkong, 2012; Youngkong et al., 2010) to diagnosis and health care applications (Pinheiro et al., 2008; Wilson et al., 2006). More recent exploration of the use of MCDA for risk assessment and management in public health have been proposed (Hongoh et al., 2011) with some early examples emerging to assess risk to Rift Valley fever (Tran et al., 2013), swine fever (de Glanville et al., 2014) and Chagas disease (Vinhaes et al., 2014). MCDA based tools have been developed to rank emerging disease threats (Del Rio Vilas et al., 2013) and a model was recently developed to assess Lyme disease management in Quebec (Aenishaenslin et al., 2013).

Deliberative MCDA as a complementary approach for CC adaptation planning

Given the considerable health impacts of climate change and anticipated effects on vector-borne disease, there is an increasing need to develop robust adaptation strategies. Climate change has been dubbed a “wicked problem” (FitzGibbon and Mensah, 2012; Head, 2008) in part due to its complex, open-

ended nature and anticipated impacts across multiple, interacting systems with many unknown synergies and scale of anticipated effects. The ability of MCDA to incorporate multiple forms of knowledge and evidence, including relative appreciations of available data, makes it well suited for complex problems. Deliberative MCDA is additionally well suited for complex problems such as climate change adaptation due to its ability to accommodate the input and perspective of multiple stakeholders.

CHAPTER 2

CRITERIA FOR THE PRIORITIZATION OF PUBLIC HEALTH INTERVENTIONS FOR CLIMATE-SENSITIVE VECTOR-BORNE DISEASES IN QUEBEC[1]

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Abstract

Prioritizing resources for optimal responses to an ever growing list of existing and emerging infectious diseases represents an important challenge to public health. In the context of climate change, there is increasing anticipated variability in the occurrence of infectious diseases, notably climate-sensitive vector-borne diseases. An essential step in prioritizing efforts is to identify what considerations and concerns to take into account to guide decisions. This study was designed to perform a comprehensive review of criteria for prioritization of climate-sensitive vector-borne diseases, assess their applicability in a context of climate change with a diverse cross-section of stakeholders in order to produce a baseline list of considerations to use in a decision-making context. Differences in stakeholder choices were examined with regards to prioritization of these concerns for research, surveillance and disease prevention and control objectives.

A preliminary list of criteria was identified following a review of the literature. Discussions with stakeholders were held to consolidate and validate this list of criteria and examine their effects on disease prioritization. After this validation phase, a total of 21 criteria were retained. A pilot vector-borne disease prioritization exercise was conducted using PROMETHEE to examine the effects of the retained criteria on prioritization in different intervention domains. Overall, considerations expressed by stakeholders for prioritization were well aligned with categories of criteria identified in previous prioritization studies. Weighting by category was consistent between stakeholders overall, though some significant differences were found between public health and non-public health stakeholders. From this exercise, a more general model for climate-sensitive vector-borne disease prioritization has been developed that can be used as a starting point for further public health prioritization exercises relating to research, surveillance, and prevention and control interventions in a context of

climate change. Multi-stakeholder engagement in prioritization can help broaden the range of considerations taken into account, offer opportunities for early identification of potential challenges and may enhance acceptability of any resulting decisions.

Keywords: participatory decision aid, multi-criteria decision analysis, disease prioritization

Introduction

Prioritizing resources for optimal response to an ever-growing list of existing and emerging infectious disease risks presents an important challenge to public health administrations and their core intervention domains (1,2). Ongoing global changes such as climate change, large scale land use transformations, increasing global travel and political instability in various regions of the world, contribute to variations in the patterns and occurrence of a number of infectious diseases, notably vector-borne diseases, which are being increasingly recognized as sensitive to weather and climate (3). Changes in terms of the season of occurrence and the geographical distribution of these diseases are increasingly anticipated as weather and climate are known to be drivers of the transmission and distribution of vector-borne diseases (4). Prioritizing resources between existing and climate sensitive vector-borne diseases is complex but a necessary reality as potentially difficult trade-offs need to be made while taking into account a diversity of viewpoints (5).

Prioritization often serves as an initial step in aligning efforts and guiding decisions within public health's various intervention domains, notably, research, surveillance, and prevention & control. As such, disease prioritization exercises have been undertaken in public health and veterinary public health contexts over the last few decades (6–20). Traditionally, where stakeholders have been

involved in these processes, with the exception of the studies by Ng and Sargeant (2012a) and Brookes et al (2014b), experts (in public health) have been the primary group included in the process. These exercises help structure reflection and guide decisions around resource allocation in order to ensure effectiveness within organisations and across various levels of government for effective public health delivery (21). An evolution in the way such exercises have been carried out over the last few decades can be seen in the examination of the literature (5) and reveals common goals and concerns that have persisted in their undertaking; notably, a push towards a systematic and transparent process and growing awareness of the increasing viewpoints that should be included in such exercises (12,21–23). Refinements to the process over time have sought to separate information on the diseases (criteria measurement) from values pertaining to prioritization concerns (criteria) in order to improve transparency of the process. The explicit and measurable aspect of these exercises is sought by defining explicit criteria on which to evaluate the diseases being prioritized. Criteria and how they are used to evaluate diseases are at the crux of the disease prioritization process. Criteria should represent core considerations or values relating to the prioritization objectives and help explicitly track relative differences between the items being prioritized (24). Additionally, since health decisions in publicly funded health care systems use tax-paying citizen's dollars to operate, in the interest of transparency and accountability, it is important to understand what concerns are held by society both to verify acceptability of potential decisions and understand where differences in values or priorities may be present in order to help bridge existing gaps; moreover, examining the impact of different methodologies on the end results constitutes another relevant issue. In the current study, we identify criteria for the prioritization of vector-borne and zoonotic diseases applicable in a context of ongoing and anticipated climate change in order to construct a more general model for disease prioritization. We then examine differences in concerns and perspectives from a set of stakeholders

with regards to prioritization of public health interventions relating to research, surveillance and prevention and control. Stakeholders working in fields both directly and not directly connected to public health were included in the process to assess similarities and differences in values held. The effect of combining current scientific knowledge with stakeholder values on disease prioritization is examined by means of a pilot prioritization exercise performed with a multicriteria decision aid process using the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) outranking method (25).

Materials and Methods

In formal decision support approaches, decision criteria are identified to assist in systematically taking into account important concerns relevant to the decision-making intervention domain. The use of a participatory multi-stakeholder processes can help contribute to a more exhaustive and transparent selection of decision criteria. Towards this end, a comprehensive review of the literature was conducted to identify the most commonly used criteria for prioritization that are relevant in a context of ongoing climate change. This was followed by a discussion and validation of the identified list with a diverse group of stakeholders. The resulting criteria were used in a pilot prioritization exercise using PROMETHEE to examine differences in stakeholder assigned weightings and their effect on prioritization under different intervention domains.

Preliminary criteria identification

A comprehensive review of infectious disease prioritization studies published between 1990 and 2014 was undertaken to identify key criteria that should be considered for inclusion in a generic model (Table III). A keyword search of the literature was carried out using a scientific database (Pubmed) with combinations of the following keywords: “emerging”, “infectious”, “communicable”,

"zoonoses", "disease" and "prioritization". Titles and abstracts were used to identify potentially relevant articles for further data extraction. Articles published in English or French pertaining to a prioritization exercise of infectious disease related items were retained for review. Additionally, relevant peer reviewed and grey literature referenced by articles retained for data extraction were also included in the review if they met the original inclusion criteria (snowball sampling) (26). Criteria and their related categories as described by citing articles were extracted from reviewed studies. As climate change may alter the season of occurrence and geographical distribution of climate sensitive vector-borne diseases (4), criteria pertaining to elements of the disease transmission process that may be affected by climate change were included. For example, whether or not conditions for transmission are already present for a disease is an important consideration in prioritization of these diseases. Conditions for transmission can relate to environmental conditions, vector or reservoir conditions. Climate change signals are inherently difficult to separate out from the multitude of other driving forces (such as land use patterns, globalization and associated transport of goods, travel, etc.) which may affect disease transmission patterns. As such, many criteria that pertain to general disease prioritization are also relevant in assessing climate sensitive vector-borne diseases such as current levels of scientific knowledge and treatment availability and therefore were included in the preliminary list. A thematic categorization of criteria coherent with original categories used by citing articles was created by the authors following the review to support criteria discussion with stakeholders and is presented along with the criteria in the results section.

Focus group discussion

Following the literature review, a focus group discussion was held with a small group of stakeholders in Quebec (Canada) to discuss concerns with regards to vector-borne diseases in a context of climate change. Prioritization of diseases

was further examined in the context of interventions for research, surveillance as well as prevention and control. Stakeholders were selected based on their concurrent participation in a separate ongoing study on West Nile virus management in Quebec. Stakeholder invitations were initially sent out to 24 individuals and organizations having previously participated in vector-borne disease consultations by the province. These organizations represent a range of civil, municipal and regional level organizations (including non-governmental environmental rights groups, forest, agriculture and human health protection society, ministry of agriculture, fisheries and food, council of the protection of patients, municipal affairs, municipal representatives from municipalities in the province, commission for health and welfare, academics, Quebec seniors rights representative group, regional public health departments and provincial blood donation services) representing the interests of various civil, municipal or regional subsets of the Quebec population. These organizations have all been in existence for over a decade. All participating stakeholders gave informed written consent prior to participation in the study.

Prior to the stakeholder meeting, participants were invited to reflect on their concerns with regards to managing infectious diseases in the context of climate change. During the focus group discussion, stakeholders began by writing down their prepared concerns. These were then compiled using a modified nominal group technique (27) and discussed with all participants. Following this, the literature identified criteria and their thematic categorizations were presented in writing and discussed with stakeholders. Stakeholder compiled concerns and literature identified criteria were compared and discussed. Stakeholders were given the opportunity to add additional criteria and clarify or reword the literature identified set in person during the discussion. Measurement scales were also discussed at this time.

Following the meeting, stakeholders were given an additional month to reflect on and validate the final list of criteria by means of two rounds of online Delphi review (28). The online review was conduted using an electronic survey that presented all retained criteria from the in-person discussion and allowed stakeholders to "vote" for the inclusion of individual criteria. Comments on the relevance of the criteria to the prioritization models could also be made at this time. Stakeholders agreed to retain any criteria which received at least one vote from a participating stakeholder. Results from the first online review were compiled and presented to stakeholders to allow further modification before the final validated set was defined. This final set was designated for inclusion in prioritization models pertaining to research, surveillance and prevention and control of infectious diseases. This project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (Comité d'éthique de la recherche en santé, CERES) (certificate number 14-025-CERES-D).

Criteria weighting

Following validation of the final list of criteria, stakeholders were asked to weight criteria according to their relative importance with regards to research, surveillance and prevention and control interventions. The purpose of this weighting exercise was to translate stakeholder value systems into numerical weights. In order to do this, stakeholders were given a Microsoft Excel spreadsheet tool and asked to distribute 100 points across the list of decision criteria included in the model. The Excel tool included the finalized list of stakeholder validated criteria, desired effect direction of criteria and measurement scales listed by category with replicated sections for each of the three intervention domains (research, surveillance, prevention and control). Stakeholders were asked to weight criteria in accordance with perceived importance taking into account their relative importance overall. Weights of zero were permitted for criteria to allow stakeholders to indicate the absence of

importance of criteria if applicable. The difference in relative weights assigned to different categories were compared between the three intervention domains (research, surveillance and prevention and control) and Welch's t-test (unequal variances t-test) were performed in R (version 3.2.2) (R Core Team (2016), Vienna, Austria, http://www.R-project.org) to test for significant differences in category weights.

Pilot prioritization of five diseases

An exploratory prioritization of five potentially climate-sensitive vector-borne diseases, Lyme, West Nile virus, chikungunya, dengue, and malaria was carried out to examine the effects of criteria weightings on disease rankings for each intervention domain. Only Lyme and West Nile virus have shown a local transmission cycle in Quebec in the last 10 years (29,30); the other three diseases currently manifest themselves as imported cases only, but local cycles may occur in the coming decades due to climate change (31–33). Lyme expansion in North America has been linked to climate change (29) and while West Nile virus expansion into North America was not directly linked to climate change, its epidemiology has been shown to be directly sensitive to climatic factors (34). A literature search was conducted pertaining to each of the diseases in order to assess and score disease performance over the criteria. The same disease assessment scores were used for each intervention domain, though weighting schemes varied as per stakeholder expressed weights. Analysis of disease performance and criteria weights was performed with the PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) in visual PROMETHEE software (version 1.4.0.0) (VP Solutions software, Brussels, Belgium, http://www.promethee-gaia.net). The PROMETHEE II method was used as it provides a complete ranking of results without incomparability (35,36). PROMETHEE methods are pair-wise comparison methods that are part of the outranking class of decision aid methods enabling comparison of multiple items

over multiple criteria with allowance for both maximization and minimization of criteria (35,36). In traditional multi-criteria type problems, incomparability can occur when one alternative performs better on one criterion and weakly on another whereas another alternative performs better on the first one's weaknesses and poorly on the first one's strengths (35,36). PROMETHEE II was designed to overcome this incomparability without scale effects (35,36). Additionally, a GAIA (Geometrical Analysis for Interactive Aid) visual analysis was also used to graphically explore decision maps. A sensitivity analysis was performed on all criteria for 1st order ranking stability within the visual PROMETHEE software in order to examine the robustness of rankings for all stakeholder weights.

Results

Literature and stakeholder identified criteria

Following an initial keyword search, the titles and abstracts of 1196 articles were scanned for relevance (Table III). This resulted in 37 studies which were retained for full text review. Five additional articles referenced within the previous set were also reviewed. From this, 26 studies explicitly reporting prioritization criteria were retained for data extraction. A summary of these studies is shown in Table IV. Studies were primarily from high income countries in North America, Europe and Asia. While prioritization exercises have taken place in developing contexts (37), none were found pertaining explicitly to vector-borne diseases in the reviewed time period. An initial list of 22 criteria was extracted from these studies. The number of criteria used ranged from as few as 5 to as many as 57 criteria. Reported sources included experts, lists from previous exercises and literature. A number of studies had shared approaches and criteria (e.g.: (6,38,39); (21,40); (7,9,41,42)) while other studies used similar concepts,

with variations in wording. The most common categories included: public health impacts, economic or market impacts, animal health impacts (generally pertaining to market impacts but also for animal-welfare), public perception and public health capacity to deal with a disease. This categorization was the basis for the final retained categories consisting of “Public Health”, “Social Impact”, “Economic”, “Animal and Environmental Health”, “Strategic and Operational” (i.e. logistics). Additionally, a “Risk and Epidemiology” category was also defined to capture elements of general disease concern such as epidemic potential, recent disease trends and proportion of susceptible population. Climate sensitive risk and epidemiology were also included in this category. As climate change will likely alter temperature and precipitation patterns with consequences for animal and vector distribution (4), criteria pertaining to existing conditions for disease transmission were included here. Commonly used prioritization criteria and their frequency were tracked across reviewed studies (see supplementary Table XXXIX in Appendix 1). Recurring relevant criteria were identified and where wording was different but pertaining to the same concept, criteria were combined and synthesized where appropriate into a shorter preliminary list of 20 criteria covering as broad a range of relevant concepts as possible for discussion with stakeholders. This number was chosen in order to present a manageable set for discussion with stakeholders. Retained criteria were then used in a pilot prioritization exercise to examine differences in stakeholder assigned weights under different intervention domains.

Table III. Article selection process for review

	Steps	Total articles
1	Initial keyword search in Pubmed of studies containing combinations of the following keywords: “emerging”, “infectious”, “communicable”, “zoonotic”, “disease” and “prioritization”.	N=1196
2	Title and abstract scan of articles from Step 1 scanned for relevance resulting in 37 studies describing describing disease prioritization studies.	N=37
3	Related peer reviewed and grey literature articles referenced by articles retained in step 2 were also scanned for relevance (snowball search).	N=42
4	Final article selection of studies in which prioritization criteria were explicitly listed or described	N=26*

*Note: In some cases, multiple articles referred to different aspects of the same study

Table IV. Summary of reviewed disease prioritization studies

Author & year	Country^	Objective	**	Criteria	Weights	#	Item type	Method overview
Carter 1991	Canada	Set priorities for national surveillance (notifiable list)	B	12	No	60	Communicable diseases	Committee (n=6) scored and discussed. Un-weighted criteria. Cut-off set for inclusion of diseases on notifiable list.
Rushdy et al 1998	UK	Rank diseases to manage resources	C	6	No	41	33 communicable diseases and 8 generic diseases	Expert opinion, questionnaire - assessed by experts in communicable diseases (n=194)
Doherty 2000	Canada	To inform resource allocation national level	B, D	10	No	43	Communicable diseases	Expert opinion and consensus of subcommittee (n=6)
Horby et al 2001	UK	Rank diseases to manage resources	B, C	5	No	69	58 pathogens and 11 generic diseases	Expert opinion (n=518)
Valenciano 2002 (InVS)	France	Determine priorities to improve knowledge, prevention and control of diseases	A, B, C	6	No	37	Non-food borne zoonoses	Expert opinion (n=10)
WHO 2002 (Dubrovnik pledge) *	WHO - 7 eastern European countries	Strengthen infectious disease surveillance systems in 7 countries of South-East Europe	B	8	No	53	Communicable diseases	Expert opinion (n=24)
Doherty 2006	Canada	Strengthen national surveillance capacities	B	10	No	48	Communicable diseases	Expert opinion and consensus of subcommittee (n=6)
McKenzie et al 2007	New Zealand	Prioritize wildlife pathogens for surveillance	B	3	No	82	Wildlife pathogens	OIE based risk assessment approach
Krause et al 2008a&b	Germany	Guide research and surveillance strategies of department	A, B	12	Yes	85	Pathogens	Expert opinion (n=11) and weighted sum aggregation
Cardoen et al 2009	Belgium	Rank food and water-borne pathogens to prioritize resource allocation for management	C	5	Yes	51	Food and water-borne zoonotic pathogens	Expert opinion (n=35) and weighted sum aggregation
Capek 2010 (InVS)*	France	Rank non-foodborne zoonoses and anticipate emerging threats linked to climate, etc.	A, B, C	6	No	37	Non-food borne zoonoses	Expert opinion (n=16)
Havelaar et al 2010	The Netherlands	Prioritized emerging zoonoses to support an early warning and surveillance network	B	7	Yes	86	Emerging zoonotic pathogens	MCDA technique. Existing list and expert opinion determined list of pathogens, weighting of criteria based on panel consultation (n=29)

Pavlin et al 2010	Pacific Island nations	Update list of pathogens to include on urgent NNDL list	B, D	12	Yes	27	Conditions/diseases assessed	Additive model - Sum of scores
Ruzante et al 2010	Canada	Framework to prioritize foodborne risks	D	4	Yes	6	Pathogen-food combinations	MCDA technique - PROMETHEE
Balabanova et al 2011	Germany	Rank infectious diseases for research and surveillance	B	10	Yes	127	Pathogens	Expert opinion (n=83) and weighted sum aggregation
Humblet et al 2012	Europe	European collaboration and agreement on priority zoonoses for surveillance and eradication	B, C	57	Yes	100	Zoonoses	MCDA technique with Expert scoring (n=40) with weighted sum aggregation and Monte Carlo simulation
Ng & Sargeant 2012a, b, 2013	Canada	Compare zoonoses priorities between Canada and the US from public and expert perspective	A	21 (59) †	Yes	62	Zoonotic diseases	Criteria elicitation - via conjoint analysis technique conducted with public (n=1500) and expert (n=1471) focus groups and surveys, summed using part-worth utility values approach
Cediel et al 2013	Colombia	Prioritize zoonoses for surveillance	B	12	Yes	32	Zoonoses	Delphi (n=12) and additive model
Del Rio Vilas et al 2013	UK	To inform management of emerging animal health related threats in UK	C	10‡	Yes	111	111 threats, 74 unique	MCDA technique - Developed threat assessment tool
Cox et al 2013	Canada	Test standardised method to prioritise infectious diseases of humans and animals that may emerge in response to CC	A	40	Yes	9	Trialed on 9 test pathogens	MCDA technique - MACBETH and additive model (n=64)
Kadohira et al 2015	Japan	Surveillance and management of zoonoses	B, C	7	Yes	98	Zoonoses	Author determined criteria, risk profiles generated and reviewed by experts (n=76) with AHP attributed weights by stakeholder groups (n=334)
Brookes et al 2014 a&b	Australia	Prioritize exotic pig diseases for management	C	9	Yes	30	Diseases	MCDA technique with stakeholder (n=81) elicited weight preference via online survey

^ Country targeted by prioritization exercise; ** A=research; B=surveillance; C=prevention & control; D=policy; #Number of diseases or pathogens prioritized

* Not peer reviewed;

†59 identified, but only 21 used in prioritization exercises ;

‡3 models (perception (3 criteria), impacts (4 criteria) and capabilities (3 criteria))

Focus group discussion

Twelve stakeholders consented to participate in a discussion held on September 29th, 2014 in Montreal, Quebec, Canada on the topic of perspectives and concerns relevant to disease prioritization in a context of climate change. One third of participants were female. All participants were between the ages of 30 and 65. Stakeholders had backgrounds in microbiology, entomology, biology, medicine, veterinary medicine and patient advocacy and hailed from a mix of both provincial and municipal organizations. Stakeholder discussions revealed coherence between stakeholder identified concerns and the literature constructed list of criteria. Further online validation by stakeholders following the initial meeting, resulted in a finalized list of twenty-one criteria (Table V). Discussions of appropriate measurement scales and direction of desired effect to assess diseases were also held and are included in Table V.

Table V. Stakeholder validated list of criteria for the prioritization of climate sensitive vector-borne diseases

Category	Criteria	Desired effect direction	Measurement units
Public Health Criteria (PHC)	PHC-01 – Reported yearly incidence of human cases in country	Maximize	0: Nil; 1: Very Low (<5); 2: Low (6-30); 3: Moderate (31-; 100): High (101-500); 5: very high (>500); 6: Unknown
	PHC-02 – Severity of the disease (both physically and mentally)	Maximize	0: Nil; 1: Low severity; 2: Moderate severity; 3: High severity; 4: Very high severity (risk of mortality)
	PHC-03 – Vulnerable groups	Maximize	0: All are vulnerable; 1: Existence of higher risk groups (e.g. 0-5yrs)
	PHC-04 – Potential to increase social inequality *	Maximize	0: No effect on social inequality; 1: Likely to exacerbate social inequality
Social Impact Criteria (SIC)	SIC-01 – Risk perception of the public	Maximize	1: Low perceived importance; 2: Moderate importance; 3: High importance
	SIC-02 – General level of knowledge, attitude and behaviour of the public	Minimize (Diseases for which the public has little knowledge of greater concern)	1: Little or no knowledge; 2: Moderate knowledge (general idea of symptoms); 3: High knowledge (can recognize symptoms and aware of transmission and treatment)
Risk and Epidemiology Criteria (REC)	REC-01 – Existence of favourable conditions for disease transmission	Maximize (diseases for which transmission conditions already favourable of greater concern)	1: Low risk (climate not suitable, no vector and no reservoir hosts); 2: Moderate risk (one of components present, either suitable climate, vector or reservoir host); 3: High risk (all components present – suitable climate, vector and reservoir host - or current or historic transmission)
	REC-02 – Epidemic potential	Maximize	1: Low risk; 2: high risk
	REC-03 – Current global trend of disease over last 5 years	Maximize	1: Stable – little to no recent local or global change in transmission; 2: unstable – recent global changes in transmission; 3: very unstable – recent local changes in transmission
	REC-04 – Proportion of susceptible population	Maximize	1: very low 0-5%; 2: low 5-10%; 3: moderate 10-25%; 4: high 25-50%; 5: very high 50+
Animal and Environmental Health Criteria (AEC)	AEC-01 – Estimated prevalence of yearly animal cases	Maximize (diseases with more cases of greater concern)	0: not transmissible to animals; 1: very low (<5%); 2: low (5-10%); 3: moderate (10-25%); 4: high (25-50%); 5: very high (50+); 6: unknown prevalence
	AEC-02 – Severity of disease	Maximize	0: Not applicable; 1: Low severity; 2: Moderate severity; 3: High severity; 4: Very high severity (risk of mortality)
	AEC-03 – Environmental or animal reservoir stage	Maximize (diseases with environmental stages of greater concern; harder to control)	1: Low risk – no independent stages that can survive in environment, water or reservoir hosts; 2: higher risk – existence of independent stages that can survive in environment, water or reservoir hosts.
Economic Criteria (ECC)	ECC-01 – Cost to provincial government	Maximize	1: low costs; (a few thousand); 2: moderate costs (hundreds of thousands); 3: high costs (millions)

	ECC-02 – Cost to private sector	Maximize	1: low costs (<100$); 2: moderate costs (<1000$); 3: high costs (>1000$)
	ECC-03 – Cost to individuals	Maximize	1: low costs (<100$); 2: moderate costs (<1000$); 3: high costs (>1000$)
Strategic and Operational Criteria (SOC)	SOC-01 – Capacity to detect and diagnose	Minimize	0: no tests, symptoms difficult to recognize; 1: distinct symptoms or existence of tests
	SOC-02 – Existence and effectiveness of current treatments	Minimize	0: no existing treatment; 1: partially effective treatment; 2: highly effective treatment available
	SOC-03 – Level of scientific knowledge of the disease	Minimize (diseases for which little is known of greater concern)	1: low – very little knowledge; 2: moderate – partial yet incomplete knowledge of disease symptoms, transmission, risk factors and treatment; 3: high – symptoms, transmission, risk factors and treatment well known
	SOC-04 – Optimization opportunities	Maximize	0: no opportunities; 1: potential opportunities
	SOC-05– Reportable disease	Maximize	0: not reportable; 1: nationally or internationally reportable

* Criteria added by stakeholders

Criteria weighting

Weighting of criteria was done individually by stakeholders and returned to the researchers by email in the weeks following the in-person focus group discussion. Ten of the original twelve stakeholders completed the criteria weighting exercise for each of the three intervention domains (research, surveillance or prevention and control). The relative importance of categories was generally similar for stakeholders across domains with no significant differences found between average category weights given to intervention domains (Fig.1). Individual stakeholder weights for all criteria are included in the supporting Information Table XXXIII-XXXV (Appendix 1). For all three intervention domains, the top three weighted categories were consistently "Public Health", "Risk and Epidemiology" and "Strategic and Operational" criteria while the bottom three categories were consistently "Animal and Environmental Health", "Economic" and "Social Impact" criteria. In the top 3, "Public Health" was generally the top weighted category in the subset with "Strategic and Operational" criteria consistently in 3rd place whereas in the bottom 3, the "Animal and Environmental" criteria category was generally top rated while "Social Impact" was either last or tied for last.

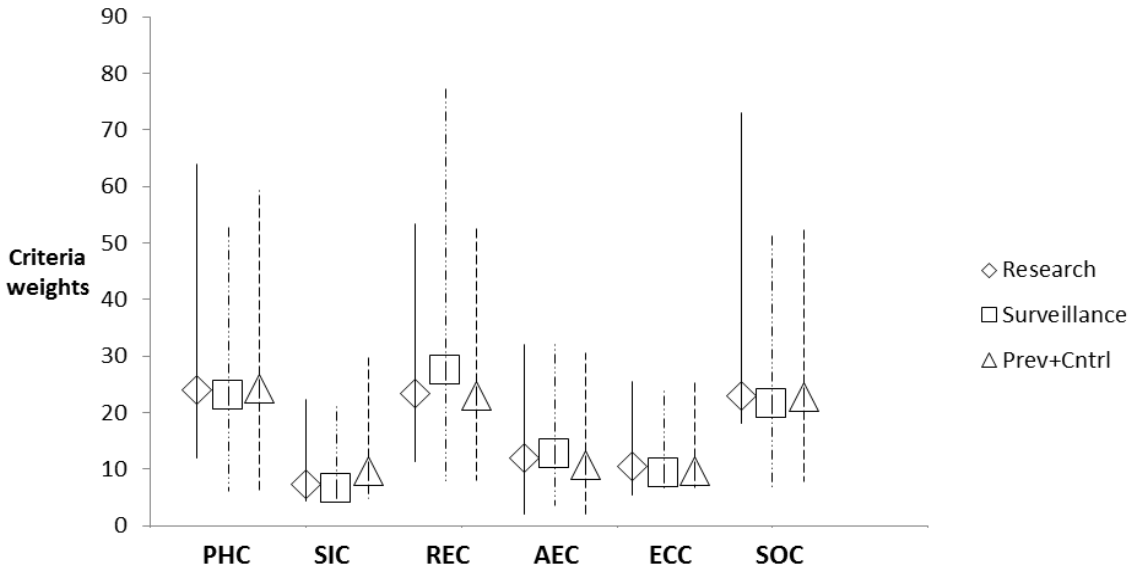

Figure 1. Criteria category weight average comparison by intervention domain

The span of stakeholder weights is indicated by the vertical lines with shaped makers indicating the intervention specific group means. Criteria categories are shown along the X axis with average weights by category shown along the Y axis. The differences between the weights given to each intervention domain (research, surveillance and prevention & control) were not found to be significantly different for any of the categories. Criteria category Legend (X axis): PHC: Public Health Criteria; SIC: Social Impact Criteria; REC: Risk and Epidemiology Criteria; AEC: Animal and Environmental Health Criteria; ECC: Economic Criteria; SOC: Strategic and Operational Criteria.

Despite similarities in the relative importance of categories, weight choice differences were observed between stakeholders and are reflected in the GAIA visual analysis of projected stakeholder weights (Fig.2). The top weighted criterion varied considerably by individual and by intervention domain though was generally from one of the top 3 weighted categories (i.e. “Public Health”, “Strategic and Operational” or “Risk and Epidemiology” categories). The least weighted criterion also varied considerably by individual and intervention domain however, given the large number of criteria, multiple criteria often shared the lowest value but were not limited in origin to only the least weighted categories (“Animal and Environmental Health”, “Economic” and “Social Impact”).

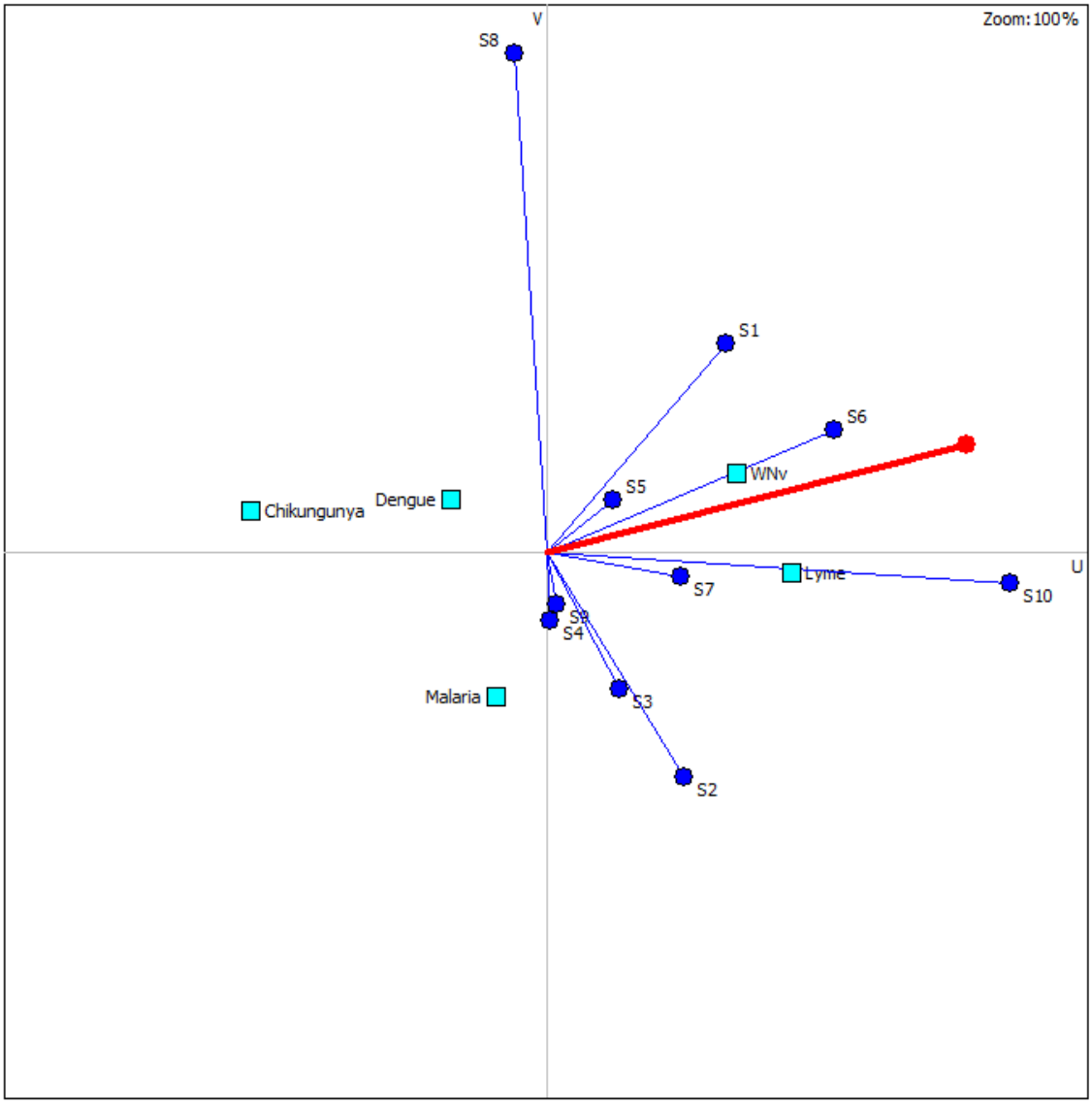

Figure 2. GAIA decision map for the "Research" intervention domain.

The bold red line represents the group decision axis (i.e. consensus ranking) with the filled circle pointing in the direction of the group ranking. Square markers represent the ranking of the different diseases in k-dimensional space (where k represents the number of criteria) projected onto a 2-dimensional plane. Diseases closest to the group decision axis are prioritized over diseases further away from the decision axis. Stakeholders 1 through 10 are represented by the blue circular markers labelled S1-S10. Stakeholders pointing in the same direction as the group decision axis are most aligned with the group ranking. Stakeholders further away in space from each other and from the group decision axis have more disparate weighting tendencies and hence perspectives. (Additional GAIA decision maps are provided in the supporting information for the "Surveillance" and "Prevention & Control" intervention domains Supplementary Fig.13-14 in Appendix 1)

The weights expressed by stakeholders not directly associated with public health organisations (n=3) were found to vary significantly (though not necessarily together) compared with the rest of the group. This was the case for the weights given to the "Public Health" category for research (p=0.011) and surveillance (p=0.016) interventions as well as the weights given to the "Risk and Epidemiology" category for prevention and control (p=0.035) and research (p=0.035) interventions. In the previously mentioned cases, the stakeholders not directly associated with public health generally attributed less weight to these categories compared to stakeholders directly working in public health. Conversely, the distribution of weights given to the "Social Impact" category for prevention and control interventions (p=0.044) and for the "Strategic and Operational" category for research (p=0.028) interventions were generally found to be higher for stakeholders not directly associated with public health.

The criterion "existence of favorable conditions for disease transmission" was weighted as the highest or second highest criterion within the "Risk and Epidemiology" category for the majority of stakeholders. Despite this, when examining its weighting across prioritization contexts, it was weighted within the top five criteria for only 5 out of 10 stakeholders in the research and surveillance intervention domains and for only 6 out of 10 stakeholders in the prevention and control intervention domain. This suggests that additional concerns (such as disease severity, level of scientific knowledge, current incidence and public risk perception) are given priority by at least half of the stakeholders for all intervention domains (i.e. risk and epidemiology characteristics are not necessarily the main priority for all stakeholders). Criteria from the "Social Impact", "Animal and Environmental Health" as well as "Economic" categories were rarely among the top 5 weighted individual criterion for stakeholders, though these do appear among the top 5 for some stakeholders across each of the intervention domains.

Pilot prioritization of diseases

The results of the pilot prioritization exercise yielded the following overall group ranking order for diseases in both the research and surveillance intervention domains: West Nile virus, Lyme, Dengue, Malaria, and Chikungunya virus. The prevention and control domain yielded a very similar ranking with malaria and dengue receiving very similar outranking scores but with malaria slightly outranking dengue as a priority for surveillance. Diseases were ranked with and without stakeholder assigned weights across intervention domains to assess dominance. No single disease was found to be dominant. Varying the disease evaluations showed sensitivity of disease rankings to their evaluations. Furthermore, different scales would produce different evaluations with potentially different rankings. As the goal of the current project was not to formally assess local disease priorities (for the creation of an official list of priority diseases), but rather to assess differences in stakeholder perspectives and examine the effect of these on potential rankings, a formal systematic assessment of sensitivity to disease scales was not performed. The retained scales allowed us to distinguish between the relative importance of diseases per criterion. Unweighted uni-criterion analysis revealed criteria for which each of the assessed diseases ranked 1st at least once. For instance, Dengue ranked 1st on the “capacity to detect and diagnose” criterion, Chikungunya ranked 1st on the “level of scientific knowledge of the disease” criterion, Lyme ranked 1st on the “current global trend” criterion, malaria ranked 1st on the “risk perception of the public” criterion and West Nile virus ranked 1st on the “epidemic potential” criterion. Group and individual stakeholder ranking results are shown in Table VI with corresponding assessment values used (based on context specific data obtained from the literature) shown in the evaluation matrix in Table VII

Table VI. Pilot prioritization of diseases for the group and by stakeholder for each intervention domain

	GRP		S1		S2		S3		S4		S5		S6		S7		S8		S9		S10	
Diseases	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi	Rnk	Phi
Research																						
West Nile virus (WNV)	1	0.08	2	0.09	3	-0.01	3	0.02	3	-0.00	1	0.10	2	0.17	1	0.10	1	0.09	4	-0.01	2	0.31
Lyme (LYM)	2	0.07	1	0.13	1	0.14	2	0.04	4	-0.03	3	-0.01	1	0.18	2	0.03	4	-0.06	3	0.00	1	0.23
Dengue (DEN)	3	-0.01	3	-0.02	4	-0.04	4	-0.03	2	0.04	4	-0.03	3	-0.07	4	0.01	2	0.08	2	0.01	4	-0.15
Malaria (MAL)	4	-0.02	4	-0.12	2	0.05	1	0.05	1	0.05	2	0.00	4	-0.08	3	0.02	5	-0.18	1	0.02	3	-0.05
Chikungunya (CHIKV)	5	-0.11	5	-0.13	5	-0.13	5	-0.08	5	-0.06	5	-0.06	5	-0.20	5	-0.16	3	0.07	5	-0.03	5	-0.35
Surveillance																						
West Nile virus (WNV)	2	0.10	2	0.02	1	0.15	3	0.02	4	0.00	1	0.15	2	0.10	2	0.15	2	0.26	1	0.04	2	0.16
Lyme (LYM)	1	0.14	1	0.18	2	0.10	2	0.04	3	0.03	2	0.08	1	0.13	1	0.13	1	0.38	2	0.03	1	0.27
Dengue (DEN)	3	-0.02	3	0.00	3	-0.01	4	-0.03	1	0.08	3	-0.01	3	-0.02	3	-0.00	3	-0.13	3	-0.01	4	-0.07
Malaria (MAL)	4	-0.06	5	-0.12	4	-0.07	1	0.05	2	0.06	4	-0.09	4	-0.06	4	-0.05	5	-0.27	4	-0.01	3	-0.03
Chikungunya (CHIKV)	5	-0.16	4	-0.08	5	-0.18	5	-0.08	5	-0.18	5	-0.13	5	-0.15	5	-0.22	4	-0.25	5	-0.04	5	-0.33
Prevention & control																						
West Nile virus (WNV)	1	0.10	1	0.14	1	0.21	3	0.02	1	0.12	1	0.10	2	0.05	1	0.10	2	0.05	1	0.05	2	0.15
Lyme (LYM)	2	0.06	2	0.11	2	0.15	2	0.04	3	-0.02	2	0.07	1	0.09	2	0.03	4	-0.03	2	0.04	1	0.14
Dengue (DEN)	4	-0.02	3	-0.03	4	-0.09	4	-0.03	2	0.02	4	-0.02	3	-0.00	3	0.02	1	0.06	4	-0.02	4	-0.07
Malaria (MAL)	3	-0.01	5	-0.12	3	-0.08	1	0.05	4	-0.03	3	0.02	4	-0.01	4	-0.01	3	-0.02	3	0.01	3	0.06
Chikungunya (CHIKV)	5	-0.13	4	-0.10	5	-0.19	5	-0.08	5	-0.09	5	-0.16	5	-0.13	5	-0.14	5	-0.07	5	-0.07	5	-0.28

GRP – overall group ranking; Rnk – rank; S1-S10 – denotes stakeholders 1 through 10; Phi – net outranking flows (combined positive and negative flows) indicating performance of each disease

Table VII. Disease evaluation matrix

Diseases	Criteria																				
	PHC1	PHC2	PHC3	PHC4	SIC1	SIC2	REC1	REC2	REC3	REC4	AEC1	AEC2	AEC3	ECC1	ECC2	ECC3	SOC1	SOC2	SOC3	SOC4	SOC5
West Nile virus (WNV)	2	2	1	1	1	2	3	2	1	5	6	4	2	1	1	1	1	0	3	1	1
Lyme (LYM)	3	2	1	1	1	2	3	1	3	5	6	2	2	2	1	2	1	1	3	1	1
Dengue (DENV)	0	4	0	1	1	1	1	1	2	2	0	1	2	3	2	1	0	1	3	1	1
Malaria (MAL)	0	4	1	2	2	1	2	1	1	2	0	0	2	3	3	1	1	2	3	1	1
Chikungunya (CHIKV)	0	1	0	1	1	1	1	1	2	2	0	1	2	1	1	2	1	0	2	1	1

Disease evaluation matrix showing evaluation scores for each of the five pilot diseases based on context specific data reviewed pertaining to each disease over all criteria.
Note: Criteria AEC3, SOC4 and SOC5 are non-discriminating with the above data set due to lack of variation between disease evaluation values but could be discriminating with different diseases or more refined data set**.** Criteria were retained in the model due to expressed interest of stakeholders.
PHC – Public health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC – Economic criteria; SOC – Strategic and operational criteria

(supporting references used for disease assessments are provided in supporting information Appendix 1).

Sensitivity analysis results with weight stability intervals for all criteria by all stakeholders for the research domain are shown in Table VIII in descending order of stability (from least stable to most stable). Five of the twenty-one criteria were found to be very stable as per the size of their stability intervals spanning almost the entire range of possible values from 0-100 for all stakeholders for the 1st order ranking. This indicates that the rank ordering of diseases would not change for any weight value given to these criteria between 0 and 100. These five criteria were “the existence of a vulnerable group”, “potential to increase social inequality”, “ability to infect the environment”, “optimization opportunities” and “reportable disease”. The remaining criteria were found to have relatively small stability intervals (<10 points) for at least one stakeholder indicating high sensitivity to assigned weights by stakeholders. The “current trend”, “cost to individuals” and “general knowledge” criteria were found to be the highly sensitive for 7, 6 and 5 stakeholders respectively. This was closely followed by “existence of favourable conditions”, “disease severity for animals”, “cost to private sector” and “public risk perception” criteria for at least 4 stakeholders. Surveillance and prevention and control sensitivity analysis results were similar and are included in the supplementary material in Appendix 1.

Table VIII. Weight stability intervals in descending order from sensitivity analysis of all stakeholders for the research domain

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
REC-03	9 (0-10)	6(2-100)	10 (0-11)	5 (0-5.5)	2 (0-8)	4 (0-10)	5 (2-6)	3 (0-4)	5 (0-6)	3 (0-6)
ECC-03	1 (0-2.5)	5 (0-100)	4 (0-6)	5 (0-11)	1 (0-9)	3 (0-11)	2 (0-100)	2 (0-4)	6 (0-8)	3 (0-8)
SOC-02	4 (3-100)	1 (0-10)	6 (0-7)	4 (0-5)	10 (4-100)	8 (2.5-100)	9 (6-11)	16 (15-100)	4 (0-5)	1 (0-100)
REC-01	9 (0-100)	4 (0-100)	3 (0-4.5)	5 (4-10)	10 (1.5-100)	5 (0-100)	6 (4.5-11)	3 (2.5-100)	5 (3.5-8)	9 (0-100)
AEC-02	4 (1.5-100)	3(0-20)	3 (0-3)	5 (0-5.5)	5 (0-100)	4 (0-100)	2 (0-4)	4 (3-100)	4 (0-5)	4 (0-100)
ECC-02	2 (0-14)	5(0-9)	2 (0.5-100)	2 (1-100)	4 (0-10)	4 (0-9)	2 (0-100)	3 (0-4)	4 (2.5-100)	4 (0-23)
SOC-01	10 (0-20)	1 (0-12)	1 (0-8)	5 (0-5.5)	5 (0-14)	6 (0-13)	6 (0-7)	16 (0-17)	4 (0-5)	1 (0-27)
PHC-01	6 (0-100)	9 (4-100)	5 (0-6)	3 (0-6)	2 (0-100)	9 (1-100)	11 (0-100)	3 (2-100)	3 (0-5)	28 (0-100)
ECC-01	2 (0-3)	5(0-13)	4 (2-100)	3 (0-100)	5 (0-11)	4 (0-9)	2 (0-100)	3 (0-3.5)	4 (2.5-100)	7 (0-15)
SIC-02	1 (0-12)	3 (0-7)	6 (4.5-100)	4 (0.5-100)	5 (0-12)	4 (0-11)	5 (0-16)	3 (0-4)	5 (3-100)	3 (0-25)
REC-04	3 (0-13)	4 (0-9)	3 (1-100)	10 (6-100)	5 (0-12)	4 (0-11)	5 (0-100)	3 (0-4)	6 (4-100)	4 (0-60)
AEC-01	3 (0-100)	3(0-100)	3 (0-4)	0 (0-100)	5 (0-100)	3 (0-100)	2 (0-100)	4 (3-100)	3 (0-5)	4 (0-100)
PHC-02	6 (0-18)	12 (0-17)	10 (8.5-100)	15 (11-100)	5 (0-14)	10 (0-18)	12 (3.5-16)	3 (0-4)	4 (1.5-100)	6 (0-31)
SIC-01	3 (0-19)	3 (0-7)	9 (7-100)	1 (0.5-100)	5 (0-12)	6 (0-13)	5 (3-16)	3 (0-20.5)	4 (3-100)	2 (0-24)
REC-02	9 (8-100)	6 (0-13)	10 (0-11)	10 (0-13)	3 (0-100)	7 (0-100)	9 (0-12)	3 (2.5-100)	5 (0-7)	10 (5-100)
SOC-03	10 (0-25)	15 (0-29)	4 (0-13)	10 (0-17)	10 (0-20)	4 (0-21)	5 (1-13.5)	10 (0-12)	5 (0-9)	3 (0-36)
PHC-03	6 (0-100)	9 (0-100)	5 (0-100)	5 (4-100)	5 (0-100)	6 (0-100)	5 (3-100)	3 (2-100)	5 (4-100)	4 (0-100)
PHC-04	2 (1-100)	0 (0-100)	5 (3-100)	2 (0-100)	3 (0-100)	4 (0-100)	3 (0-100)	3 (0-100)	6 (3.5-100)	2 (0-100)
AEC-03	3 (0-100)	3(0-100)	5 (0-100)	5 (4.5-100)	5 (0-100)	4 (0-100)	2 (0-100)	4 (0-100)	6 (0-100)	3 (0-100)
SOC-04	3 (0-100)	3 (0-100)	1 (0-100)	1 (0-100)	3 (0-100)	4 (0-100)	1 (0-100)	3 (0-100)	6 (0-100)	0 (0-100)
SOC-05	1 (0-100)	0 (0-100)	1 (0-100)	0 (0-100)	2 (0-100)	1 (0-100)	1 (0-100)	5 (0-100)	6 (0-100)	1 (0-100)

S1-S10 – denotes stakeholders 1 through 10; Stakeholder assigned weights are given for all criteria followed by the stability interval in parentheses over which the ranking order for the 1st position items are maintained. PHC – Public Health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC - Economic criteria; SOC – Strategic and operational criteria

Discussion

The current study solicited a variety of stakeholder perspectives and concerns. These were assessed in conjunction with current scientific knowledge to construct general models for the evaluation of vector-borne disease priorities for public health interventions pertaining to research, surveillance and, prevention and control of infectious diseases in a context of climate change. The models constructed featured 21 criteria with corresponding measurement scales and weighting schemes as expressed by stakeholders. This study did not aim to predict which diseases might be sensitive to climate change, but rather set out to identify the primary concerns of a cross-section of society with regards to vector-borne diseases in these contexts. Furthermore, while a pilot prioritization was presented, this was done for illustration purposes only and should not be interpreted as a formal assessment of local priorities as only data from the literature was used to score diseases. Additional data as well as further discussion with experts and stakeholders is required to validate these findings.

Prioritizing diseases to optimize public health interventions is a complex process due to the numerous perspectives that should be taken into account and potentially conflicting trade-offs that may arise in integrating these perspectives into public health decisions. The review of previous disease prioritization exercises shows how common criteria and categories recur across studies (6–20). This may be due in part from the cumulative learning gained from previously published studies, but may also be representative of shared core concerns which translate into a set of common decision criteria that remain applicable across public health contexts. “Risk and epidemiology” related concerns were found to be dominant among stakeholders in our study with “existence of favourable conditions for disease transmission” among the highest weighted within the category; however, with respect to the other criteria included by stakeholders for

prioritization of vector-borne disease in a context of climate change, they were found to be similar to previous studies, even though not directly pertaining to climate change. In other words, values and concerns evoked under climate change appear similar to those evoked under other contexts; however, what is emphasized are which diseases come into "range" (i.e. risk and epidemiology related criteria). While our study included similar categories of criteria to previous prioritization exercises, detailed direct comparisons cannot be made between studies since the prioritization objectives and approaches differed.

Criteria weighting schemes expressed by stakeholders in our study tended to be broadly similar across categories. This may in part be due to the set of participating stakeholders that were selected based on their concurrent participation in a separate study on West Nile virus interventions. However, it should be noted that final rankings are not driven by stakeholder weightings alone, but rather reflect disease scores over criteria resulting from an assessment of existing literature evidence. In this exercise stakeholders were included to provide a view of concerns expressed by Quebec stakeholders to prioritize diseases of interest for the Quebec context. Within category weights and weightings by stakeholders not directly affiliated with public health related organisations were found to be different with the later significantly different from the rest of the group. These differences resulted in different individual stakeholder disease rankings (i.e. priorities) (Table VI). Differences in weights between public health and non-public health groups may in part be explained by differences in perceived responsibility or accountability between these groups (43). The observed differences in individual priorities (i.e. stakeholders rankings) helps underline the importance of including a wide array (various sectors, mandates, demographic profiles) of stakeholders in the processes in order to contribute to the inclusion of a representative set of societal concerns and perspectives in the decision analysis process. For certain intervention domains

such as surveillance, public health perspectives may be one of the most important to take into account; however, with regards to publicly funded research interventions, it may be of interest to ensure that resulting decision priorities are made coherent with socially held values. With regards to the disease prevention and control domain, understanding and attempting to integrate different perspectives may help pinpoint areas where additional information needs exist. For example, significant differences were found for the "social impact" and "risk and epidemiology" categories suggesting that important differences may exist between public health experts and the general public with regards to risk perception, knowledge and risk assessment of disease threats. Differences in risk perception between the general public and experts have been observed in previous studies (44–46).

Few studies involve the public in their consultation process, and generally involve only a narrow range of participants in the process. Involvement of a diversity of participants (researchers, government, public health personnel, and non-technical citizens) in the criteria and preference elicitation process can help ensure that a broad set of value perspectives are considered. An attempt at including a broader range of voices in the vector-borne disease prioritization process has been done in the current study. While previous studies have contrasted public and expert rankings (47,48), the current study demonstrated a potential method for how to include these voices in the same consultation exercise in order to provide an opportunity for shared knowledge exchange and discussion of concerns between groups.

Although we performed a combined group ranking analysis, we were less interested in comparing the average of perspectives, but rather were interested in understanding what points groups differ on. This type of information should be of interest to decision makers as it provides an opportunity to understand what lies at the heart of different group's perspectives and may provide an opportunity

for insight into the effect of eventual decisions. For example, for those groups where Malaria was ranked highest as a result of high expressed concern regarding severity and risk perception (i.e. weights given to these criteria were higher), a decision not to prioritize malaria could be met poorly by these concerned groups, however, additional information could be provided alongside eventual ranking results in order to reassure concerned groups such as the status of current surveillance and monitoring efforts in Canada (via mandatory reporting of detected cases and a strong public health system) and therefore low risk of endemic transmission in Canada (31).

From a public policy point of view, ensuring that resulting decisions are well aligned with publicly held values should be of interest and is something that is possible to explore with the current approach. The use of formal prioritization approaches is evolving. Who to include in the process is a consideration that should be regularly revisited by decision makers. The challenge becomes how to process the range of viewpoints consulted during analysis. Should different viewpoints be weighted equally? Should all groups be consulted primarily to elicit the most comprehensive range of viewpoints or are related weightings by different stakeholder groups useful and necessary? Key participant profiles representing the viewpoints of various societal groups can be constructed and has been used before in environmental decision making processes (49,50). The consistency of weighting tendencies within stakeholder groups was not assessed in the current study given the small number of participants; however, given a larger sampling, the consistency of weighting trends within groups could be further examined.

Disease prioritization exercises can assist in providing public health planners and policy makers with a synthesis of current knowledge on diseases as well as a degree of professional and public perspectives on the subject. Kadohira and colleagues remind us that prioritization should be “risk-based (...) systematic,

empirical, quantitative, easy to implement, based on good science, transparent, flexible, reproducible and informative to public policy"(23). Furthermore, regular updates to any prioritization exercise are required in order to take into account new information as it becomes available. This includes both updates to disease status information as knowledge on the subject evolves but also consideration of new criteria to include in order to better adapt the models to the specific prioritization contexts and needs of users as their experience with the prioritization process evolves. The approach used in the current study offers an opportunity to identify concerns held by various groups and provides a method to examine the effect of these differences in stakeholder values (if they exist) on disease rankings. The inclusion of diverse voices enriches the process and provides further opportunities to identify additional knowledge gaps and data needs that go beyond an assessment of available evidence thus contributing to a knowledge rich process.

In the current study, proximal (diseases currently susceptible to transmission in the local area) and severe diseases where few treatment options currently exist were ranked highest. When and where data are available, this type of assessment can be performed for diseases both endemic and those not yet present in an area of interest. In allocating health resources, a process for accounting and evaluating diverse interests is essential and can be formally integrated in participatory decision aid processes as these help structure and add transparency to the decision process, in a manner which is compatible and coherent with currently held social values.

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Conflicts of interest

All authors declare that they have no conflicts of interest.

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CHAPTER 3

MULTI-STAKEHOLDER DECISION AID FOR IMPROVED PRIORITIZATION OF THE PUBLIC HEALTH IMPACT OF CLIMATE SENSITIVE INFECTIOUS DISEASES[2]

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Abstract

The effects of climate change on infectious diseases are an important global health concern and necessitate decisions for allocation of resources. Economic tools have been used previously; however, how prioritization results might differ when done using broader considerations identified by local stakeholders has yet to be assessed. A multicriteria decision analysis (MCDA) approach was used to assess multi-stakeholder expressed concerns around disease prioritization via focus groups held in Quebec and Burkina Faso. Stakeholders weighted criteria and comparisons were made across study sites. A pilot disease prioritization was done to examine effects on disease rankings. A majority of identified criteria were common to both sites. The effect of context specific criteria and weights resulted in similar yet distinct prioritizations of diseases. The presence of consistent criteria between sites suggests that common concerns exist for prioritization; however, context-specific adjustments reveal much regarding resource availability, capacity and concerns that should be considered as this impacts disease ranking. Participatory decision aid approaches facilitate rich knowledge exchange and problem structuring. Furthermore, given multiple actors in low- and middle-income countries settings, multi-actor collaborations across NGOs, local government and community are important. Formal mechanisms such as MCDA provide means to foster consensus, shared awareness and collaboration.

Keywords: participatory decision aid, multi-criteria decision analysis, infectious disease prioritization

Introduction

Infectious diseases cause considerable health burden in low- and middle-income countries and continue to be of global concern with ongoing climate change. Health care systems in many African countries often struggle to meet existing demand [1] and the ongoing impact of climate change on infectious diseases, while important, cannot be approached as merely a future scenario, but requires addressing current infectious disease threats as these are likely to be exacerbated with further climate change [2]. Low- and middle-income countries carry a significant share of the global burden of disease, with infectious diseases still accounting for a significant share of the burden [3,4]. Many of these diseases, such as malaria and dengue, are vector-borne (mosquito) and known to be sensitive to climate [5–8]. Mosquitoes do not regulate their own body temperature but rather adjust their behaviour as a result of changing temperature and precipitation conditions [9]. Much debate has been had over the specific role climate will play in changing disease dynamics [10–14], yet, the compounded effect of multiple factors sensitive to climate is likely to continue to have important consequences for health [2], especially in many regions of Africa where an important part of the population depends on subsistence agriculture for survival and where access to safe water can be a challenge. Furthermore, although progress has been made in reducing burdens of some diseases such as malaria [3], emerging diseases such as Ebola threaten to overwhelm already challenged health services [15,16]. In all countries, but particularly so when basic public health services and capacity are challenged, choices must be made with respect to allocation of limited financial and health care resources [1]. Potentially conflicting notions such as the burden of disease and value for money (cost-effectiveness) are important decisional considerations [17]. Various time-based metrics such as quality-adjusted life years (QALY) and disability-adjusted life years (DALY) have been used as part of cost-effectiveness calculations to guide health

priority settings (e.g. WHO-CHOICE) [18–20]. Although cost-effectiveness analysis permits an appreciation of the relative merits of investing in one intervention or disease versus another, this approach alone is often not well suited for taking a broader set of social benefits into account and furthermore, has been criticized for setting a monetary value on health [21–24]. In the context of managing climate sensitive infectious diseases, a number of other important considerations and stakeholder perspectives need to be taken into account including the sustainability of planned interventions or effect on equity of decisions made [25]. In low- and middle-income contexts, these decisions are often made by external funders or based on region-aggregated data and thus it is important to explore considerations expressed by local stakeholders, and examine what effect these may have on disease prioritization.

A number of prioritization initiatives have been carried out in various contexts [25–27] and a recent review by McGregor and colleagues noted at least 12 different strategies used in these exercises [25]. Two-thirds of studies reviewed by McGregor made use of criteria to assist in ranking with criteria ranging from the population under study, health system capacity and feasibility [25]. Although the search for a 'gold standard' approach may not be appropriate [28], the use of a strategy in line with basic prioritization guidelines [29] ensuring the desired principles of inclusiveness, and transparency, is desirable [25]. Participatory decision aid approaches such as multi-criteria decision analysis (MCDA) have been used to rank items such as diseases [27,30] and interventions [31] based on a list of identified decision criteria in order to help improve the assessment of the relative merits and trade-offs of the items under consideration. In a prioritization exercise, the process chosen for prioritization is often as important as the results of the process itself and a participatory process involving local stakeholders can serve as a starting point to examine local concerns and explore the potential differences between these and external concerns with

regards to disease management priorities. Furthermore, a participatory approach can help promote proactive engagement of stakeholders toward the solution process. In studying climate sensitive infectious diseases in Quebec (QC), a broad set of criteria were identified. These criteria were assessed with stakeholders in QC and Burkina Faso (BF) to validate their general applicability in different contexts. A pilot prioritization exercise was carried out with the identified criteria on five mosquito-borne diseases to examine differences in stakeholder expressed priorities and effects on disease rankings.

Methods

A cross-sectional comparison of criteria selected for climate sensitive infectious diseases priority setting was carried out in Quebec (QC) and Burkina (BF). Criteria selected at both sites were compared in order to 1) identify commonalities and specificities of perspectives for prioritization of climate sensitive infectious diseases with the overall goal of reducing their public health impact and to 2) examine the potential effect of criteria on disease prioritization results.

For the exploration of local concerns and their effect on disease prioritization, a participatory decision-aid methodology was adapted from an existing MCDA exercise previously used to model vector-borne disease management [31]. This approach has two main phases - a 'problem structuring' phase - where the decision context is described including defining the important decisional concerns (criteria) and their weights according to stakeholders as well as identifying relevant items and their assessment over the identified criteria. This is followed by a 'decision analysis' phase - where an aggregation of elements identified in the first phase is performed with an MCDA analysis tool to produce a relative ranking of the items under consideration. The 'problem structuring' phase is enriched when performed with a varied group of stakeholders, allowing

for the integration of multiple perspectives, and helping to build a common understanding and vision of the decision problem. All participants gave written informed consent for inclusion prior to participation in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol for this project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (Comité d'éthique de la recherche en santé, CERES) (certificate number 14-025-CERES-D) and by the Comité d'éthique pour la recherche en santé in Burkina Faso (Deliberation number 2015-02-019) prior to commencement of the study.

Stakeholders

Two focus group discussions were held within a six-month interval. The first was held with stakeholders in Quebec, Canada (QC) in September 2014 and the second was held with stakeholders in the capital city of Ouagadougou in Burkina Faso (BF) in February 2015. Stakeholders in QC were selected based on concurrent participation in a separate study on West Nile virus management in QC and stakeholders in BF were similarly selected from a concurrent study on malaria management in BF. Stakeholders in QC had diverse backgrounds including microbiology, entomology, and public health and were from organizations previously consulted for vector-borne disease management interventions in the province. Stakeholders in BF had backgrounds ranging from entomology, environmental management and public health.

Criteria identification

A review of the literature of infectious disease prioritization studies published prior to 2014 was conducted to identify a preliminary list of criteria commonly used in these types of exercises. Stakeholders were then invited to identify their concerns with respect to disease management in a context of

ongoing climate change. Following discussion of these concerns, criteria identified from the literature were proposed and discussed with stakeholders. These criteria were aligned and adjusted as necessary for the local context. This phase was first completed in QC. The final list of criteria identified in QC was then discussed and modified with stakeholders in BF.

Criteria weighting

Following both discussions, stakeholders were asked to weight criteria in order to translate their conceptual value system into numerical weights. For the weighting exercise, stakeholders were given a Microsoft Excel spreadsheet tool and asked to distribute 100 points across the list of decision criteria included in the model. Weights of zero were permitted for criteria to allow stakeholders to indicate the absence of importance of criteria if applicable. The difference in retained criteria and the relative weights assigned to different categories were compared between the two regions and Welch's *t*-test (unequal variances *t*-test) was performed in R (version 3.2.2) to test for differences in the mean category weights.

Pilot prioritization of five diseases

An exploratory prioritization of five mosquito-borne diseases, chikungunya (CHIKV), dengue (DENV), lymphatic filariasis (LF), malaria (MAL) and West Nile virus (WNV) was carried out to examine the effects of criteria weightings on disease ranking in both QC and BF contexts. In the current study, participating stakeholders were asked to weight criteria (not the diseases themselves). A literature search was conducted pertaining to each of the five diseases in order to assess and score disease performance on all criteria contextualized for the two regions (see supplementary documentation). Analysis of the performance and criteria weights was performed with the PROMETHEE

method (Preference Ranking Organization Method for Enrichment Evaluations) in visual PROMETHEE software (version 1.4.0.0).

Results

Stakeholders and criteria

Twelve stakeholders agreed to participate in the focus group discussion held in Quebec (QC) in September 2014 and fifteen stakeholders consented to participate in the focus group discussion held in Burkina Faso (BF) in February 2015. Six categories of criteria - “Public Health”, “Social Impact”, “Risk and Epidemiological”, “Animal and Environmental Health”, “Economic” and “Strategic and Operational” - and twenty criteria were initially identified from the literature based on considerations and criteria most commonly used in similar research [26,27,32–36]. Stakeholder concerns with respect to climate sensitive infectious diseases were discussed in Quebec and Burkina Faso. This was followed by a discussion of the preliminary list of literature identified criteria. A majority of stakeholder identified concerns were found to overlap with the literature identified criteria. Based on the preliminary list, twenty-one criteria were proposed by QC stakeholders and twenty-six were proposed by BF stakeholders (Table IX). From the list of twenty-one criteria identified in QC, one criterion was removed in BF as not found relevant by stakeholders (“potential to increase social inequality”), two criteria were modified with context specific precisions for BF (the notion of costs assumed by NGOs was added to the private sector criteria and the notion of costs assumed by families was added to the individual criteria) and 6 additional criteria were added pertaining to risk perception of health agents, decision makers, foreign community, conditions and access to treatment as well as the status of the disease as new or not for the country in BF (Table IX). Eighteen criteria were common to both regions and included criteria relating to

current human cases, animal cases, disease severity, transmission potential and recent trends, costs, as well as the existence and ability to treat the disease (Table IX).

Table IX. Criteria for the prioritization of climate sensitive infectious diseases (List of criteria identified and validated by focus groups participants in Quebec (Canada) and Burkina Faso.)

Category	Criteria	Quebec (Canada)	Burkina Faso
Public Health Criteria (PHC)	PHC-01 – Current incidence of human cases in country	X	X
	PHC-02 – Severity of the disease (both physically and mentally)	X	X
	PHC-03 – Vulnerable groups	X	X
	PHC-04 – Potential to increase social inequality *	X	
	PHC-05 – New disease †		X
Social Impact Criteria (SIC)	SIC-01 – Risk perception of the public	X	X
	SIC-02 – General level of knowledge, attitude and behaviour of the public	X	X
	SIC-03 – Risk perception of health workers †		X
	SIC-04 – Risk perception of decision makers†		X
	SIC-05 – International position with regards to the disease †		X
Risk and Epidemiology Criteria (REC)	REC-01 – Existence of favourable conditions for disease transmission	X	X
	REC-02 – Epidemic potential	X	X
	REC-03 – Current global trend of disease over last 5 years	X	X
	REC-04 – Proportion of susceptible population	X	X
Animal and Environmental Health Criteria (AEC)	AEC-01 – Incidence of animal cases	X	X
	AEC-02 – Severity of disease	X	X
	AEC-03 – Can infect environment	X	X
Economic Criteria (ECC)	ECC-01 – Cost to the government	X	X
	ECC-02 – Cost to private sector (and NGOs) †	X	X
	ECC-03 – Cost to individuals (and families) †	X	X
Strategic and Operational Criteria (SOC)	SOC-01 – Capacity to detect and diagnose	X	X
	SOC-02 – Existence and effectiveness of current treatments	X	X
	SOC-03 – Level of scientific knowledge of the disease	X	X
	SOC-04 – Optimization opportunities	X	X
	SOC-05– Reportable disease	X	X
	SOC-06 – Access to treatment†		X
	SOC-07 – Adequate conditions to treat the disease †		X

* Criteria added in Quebec (Canada)

† Criteria added or modified in Burkina Faso (Africa)

Criteria weighting

Ten stakeholders from each region completed the weighting exercise. The range of weight values and group weight average for criteria are shown for both

groups in figure 3. Although specific criteria were not identical in the two regions, the criteria categories were the same in the two regions and as such minimum, maximum and mean criteria weight by category are compared (Figure 1). Mean criteria category weights were similar between both regions except for the “Risk and Epidemiology” ($p = 0.001$) and “Economic” ($p=0.008$) criteria categories which were found to be significantly different.

In QC, the “Public Health” criteria category received the highest weight average followed by “Risk and Epidemiology”, “Strategic and Operational”, “Animal and Environmental Health”, “Economic” and “Social Impact” criteria categories the last two of which were tied for last place. In BF, “Strategic and Operational” category received the highest weight average for the group of stakeholders followed by, “Public Health”, “Economic”, “Risk and Epidemiology”, “Social Impact” and “Animal and Environmental Health” criteria categories.

The weight span for categories was generally narrower among stakeholders in QC. The range from minimum to maximum weight per category spans approximately 15 points for all categories by QC stakeholders whereas the weight ranges span from 5 to 35 for categories by stakeholders in BF (Figure 3). The two categories with the largest weight discrepancy in BF were the “Public Health” criteria category and the “Strategic and Operational Criteria” category, both of which were also the highest weighted categories overall for this region.

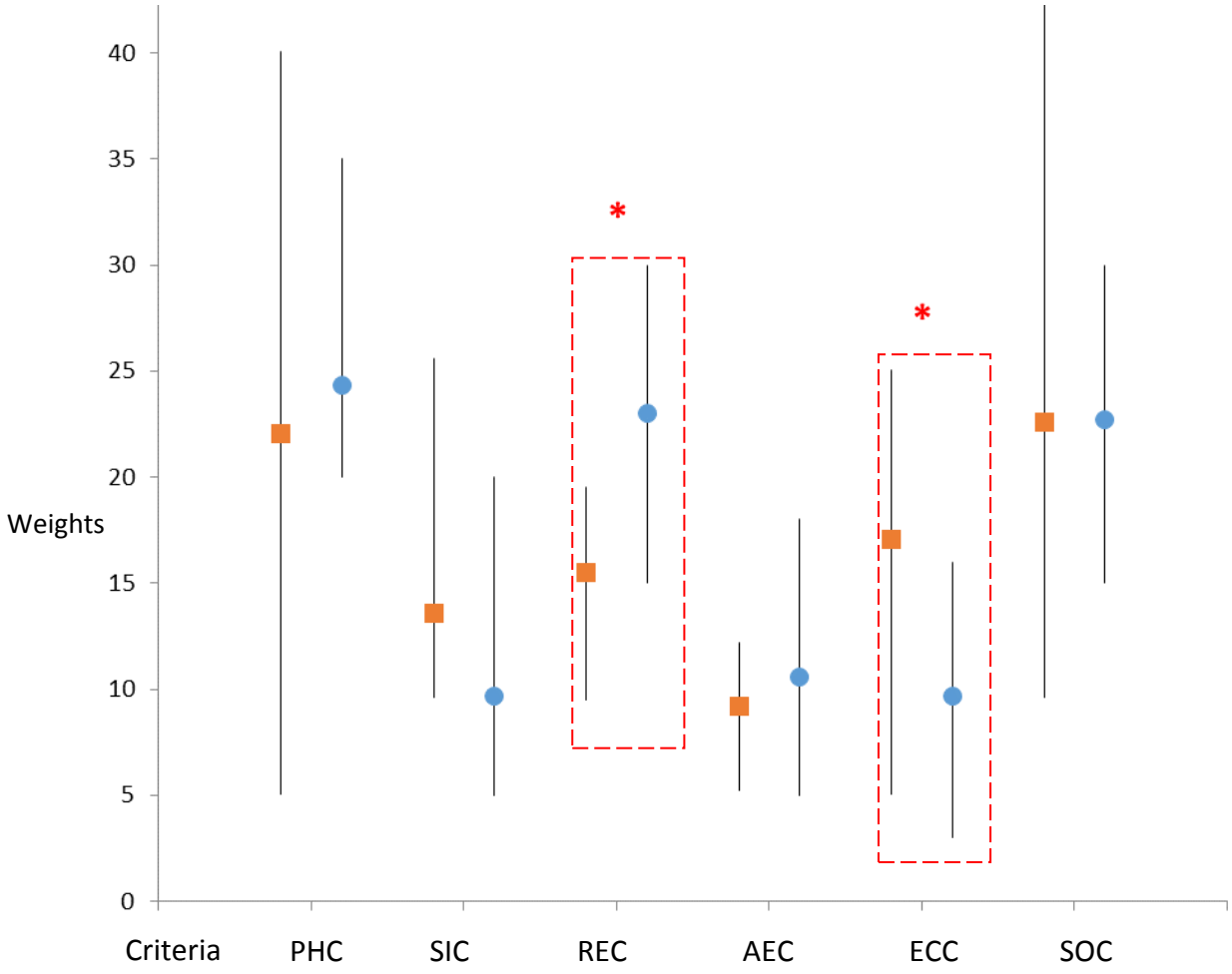

Figure 3. Average weighting of decision criteria categories by regions

(Burkina Faso represented by red square markers and Quebec represented by blue circular markers). Criteria categories are shown along the X axis and average weights by category are shown along the y axis. Bars indicate the stakeholder assigned weight ranges for criteria categories. The differences between the two groups (BF and QC) were found to be significant for the "Risk and Epidemiology" (REC) and "Economic" (ECC) categories only (unequal variance t-test, $p < 0.5$). Criteria category Legend: PHC: Public Health Criteria; SIC: Social Impact Criteria; REC: Risk and Epidemiology Criteria; AEC: Animal and Environmental Health Criteria; ECC: Economic Criteria; SOC: Strategic and Operational Criteria.

Pilot prioritization of diseases

The five pilot diseases, *CHIKV*, *DENV, LF, MAL*, and *WNV* were assessed using context specific data for each region obtained in the literature and via discussion with stakeholders (Table X and XI with references used for these assessments provided in supplementary documentation). The resulting data and weights were analyzed using a MCDA framework and resulted in differences in the relative importance (i.e. prioritized importance) of the diseases between the two regions (Table XII). In QC, the resulting disease prioritization order was: *WNV, MAL, DENV, CHIKV* and *LF,* while in BF, the resulting disease prioritization order was: *DENV, MAL, CHIKV, LF* and *WNV*.

Table X. Pilot climate sensitive infectious disease criteria evaluations for Burkina Faso (Disease evaluation matrix showing evaluation scores for each of the five pilot diseases based on context specific data reviewed pertaining to each disease over all criteria).

Diseases	Criteria																										
	PHC1	PHC2	PHC3	PHC5	SIC1	SIC2	SIC3	SIC4	SIC5	REC1	REC2	REC3	REC4	AEC1	AEC2	AEC3	ECC1	ECC2	ECC3	SOC1	SOC2	SOC3	SOC4	SOC5	SOC6	SOC7
Malaria (MAL)	4	4	1	0	3	3	2	3	2	3	2	1	5	0	0	2	3	3	2	1	2	3	1	1	1	1
Dengue (DENV)	6	4	0	0	2	2	2	1	1	3	2	2	5	6	1	2	2	2	2	1	1	3	1	1	1	1
Lymphatic filariasis (LF)	4	3	0	0	2	2	1	1	1	3	2	1	5	6	1	2	2	2	2	1	2	3	1	1	2	2
Chikungunya (CHIKV)	6	2	0	0	1	1	1	1	2	3	2	3	5	6	2	2	2	2	2	1	0	2	1	0	1	1
West Nile virus (WNV)	6	2	0	0	1	1	1	1	1	3	2	1	5	5	4	2	1	1	1	1	0	3	1	0	1	1

Note: Criteria PHC5, REC1, REC2, REC4, AEC3, SOC1, SOC4 non-discriminating with the above data set due to lack of variation between diseases but could be discriminating with different diseases or more refined data set. Criteria were retained in the model due to expressed interest of stakeholders.

Table XI. Pilot climate sensitive infectious disease criteria evaluations for Quebec (Disease evaluation matrix showing evaluation scores for each of the five pilot diseases based on context specific data reviewed pertaining to each disease over all criteria).

Diseases	Criteria																				
	PHC1	PHC2	PHC3	PHC4	SIC1	SIC2	REC1	REC2	REC3	REC4	AEC1	AEC2	AEC3	ECC1	ECC2	ECC3	SOC1	SOC2	SOC3	SOC4	SOC5
Malaria (MAL)	0	4	1	1	2	1	3	1	1	5	0	0	2	2	1	1	1	2	3	1	1
Dengue (DENV)	0	4	0	1	1	1	1	1	3	5	0	1	2	2	1	1	1	1	3	1	0
Lymphatic filariasis (LF)	0	3	0	1	1	1	2	2	1	5	0	1	2	1	1	1	1	2	3	1	0
Chikungunya (CHIKV)	0	2	0	1	1	1	1	1	3	5	0	2	2	1	1	1	1	0	2	1	0
West Nile virus (WNV)	1	2	1	1	1	2	3	2	1	5	6	4	2	2	1	1	1	0	3	1	1

Note: Criteria PHC4, REC4, AEC3, ECC2, ECC3, SOC1, SOC4 non-discriminating with the above data set due to lack of variation between diseases but could be discriminating with different diseases or more refined data set**.** Criteria were retained in the model due to expressed interest of stakeholders.

Table XII. Pilot prioritization of climate sensitive infectious diseases by regional context

Diseases	Burkina Faso		Quebec (Canada)	
	Rank	Phi	Rank	Phi
Malaria (MAL)	2	0.10	2	0.05
Dengue (DENV)	1	0.26	3	0.03
Lymphatic filariasis (LF)	4	-0.11	5	-0.25
Chikungunya virus (CHIKV)	3	0.03	4	-0.02
West Nile virus (WNV)	5	-0.27	1	0.19

Sensitivity analyses were performed to examine the weight stability intervals of criteria with respect to the 1st order ranking of the diseases. The range of the stability interval indicates the range of weight values for which the 1st order ranking remains unchanged. The narrower the stability interval, the more sensitive a criterion is to changes in assigned weight values and values assigned outside of this stability interval will result in a different rank ordering of the diseases. In Burkina Faso, the most sensitive criteria category was the “Social Impact” category with all criteria from this category found to be highly weight sensitive (stability interval size of 10 points or less) for at least one stakeholder. The most stable category was the “Risk and Epidemiology” category with only one out of four criteria found to be highly weight sensitive for stakeholders. Other relatively weight-insensitive criteria included “new disease”, “existence of favourable conditions for disease transmission”, “epidemic potential”, “proportion of susceptible population”, “can infect environment”, “cost to individuals and families” as well as “optimization opportunities”. All other criteria were found to have a narrower weight stability interval for at least one stakeholder. Weights and stability intervals for stakeholders from Burkina Faso are included in the supplementary information Table XXXIX (Appendix 2). In Quebec, all categories displayed sensitivity for at least one criterion across stakeholders. Eight criteria were found to have large weight stability intervals across stakeholders in this region and included “current incidence of human cases in country”, “potential to increase social inequality”, “general level of knowledge,

attitude and behaviour of the public", "proportion of susceptible population", "incidence of animal cases", "can infect environment", "cost to individuals" and "optimization opportunities". Once again, all remaining criteria displayed narrower stability intervals for at least one stakeholder (see supplementary Table XL for QC weight stability intervals – Appendix 2).

Discussion

Criteria and Context

The presence of consistent criteria, such as the severity of a disease and risk perception, suggests that similar concerns may apply across regions when prioritizing resources to reduce the public health impact of diseases. Some of these potentially generalizable dimensions have been seen in previous studies with the most common categories pertaining to minimizing the burden on the population, accounting for the existing health system capacity and feasibility of management [25]. In the current study, in addition to the criteria common to both regions, a number of modifications were made by stakeholders in each region in order to clarify and add relevance pertaining to the decision context of the region. These adjustments reveal important details with respect to resource availability, capacity and concerns that should be taken into account when discussing and planning prioritization of infectious diseases.

Although the notion of 'equity' was included by QC stakeholders (desire to reduce social inequalities in health) and is frequently raised in Global health related funding of projects [37] and prioritization initiatives [38], this concept received no traction with stakeholders in BF and as such was excluded for this region. A similar finding has been reported by authors in other studies [39,40] with potential explanations spanning from cultural beliefs regarding inequity in society, to lack of exposure to this concept in school curriculums among others

reasons [39]. The choice of terminology to describe the concept may also have been a factor in the lack of traction of this criterion. Further qualitative studies would be warranted to expand our understanding of this discrepancy.

The three cost-related criteria identified in QC were retained by stakeholders in BF with modifications in order to align these criteria with the realities of the decision context there. The “cost to private sector” criterion was amended to include cost to NGOs and the “cost to individuals” criterion was amended to include cost to families. These modifications contribute to our understanding of the contextual differences between these two regions and how they affect local decision making. BF is ranked 181 out of 187 countries on the Human Development Index (HDI) and is considered to be among the poorest countries in the world [41]. The financial reality of disease management in BF is that most funds for disease management and certain targeted intervention programs are externally funded by NGOs and international aid programs. Some individual treatments for children are covered by NGOs but many individual treatment costs are assumed by individuals. Illness entails days of work lost to seek treatment by individuals and family members to care for them. Quebec in contrast, has a system of universal health care funded by government collected taxes for treatment of individuals, paid sickness days for a majority of workers and dedicated means to implement disease management programs (Canada ranked 8th on the HDI [41]).

The focus group discussion with stakeholders in BF took place in the midst of the Ebola outbreak that was ongoing in the West African region. Although no cases of Ebola were reported in BF, the threat and fear of the disease was at the forefront of the minds of all. The effect of the neighboring Ebola crisis likely had a significant impact on the criteria discussed by stakeholders in BF as illustrated by the BF specific criteria added by stakeholders. These included criteria pertaining to the disease being “new” for the region, risk perception by various groups as

well as criteria pertaining to access to treatment and conditions for treatment. The risk perception criteria in particular capture the concern expressed by stakeholders as to the important potential differences between the level of threat perceived by health workers, decision makers and the international community. Moreover, access to treatment and availability of adequate conditions to treat a disease are part of the reality of the health management context in BF, but were also brought up as a direct response to what was observed in neighboring countries during the Ebola crisis such as limited availability of potential vaccines to treat the disease and access only to select patients at the time.

Criteria weighting

The large weight span range among stakeholders in BF compared with QC stakeholders suggests stronger consensus or alignment of values among this later group of stakeholders even if individuals came from different sectors. The focus group discussion in QC was coherent with a potential categorical separation between economic concerns and more feasibility related concerns as found within the strategic and operational considerations category; however, during the focus group discussion in BF, all feasibility concerns were first and foremost related to economic concerns. “Economic” concerns such as the instability of funds were a topic that was brought up repeatedly throughout the course of the discussion. Lack of autonomy with regards to funding decisions can be crippling and frustration could be heard from stakeholders during discussion regarding the inability of researchers to select their own research topics due to financial priorities imposed by foreign investors. The finding of “Strategic and Operational” concerns being generally weighted above “Public Health” concerns (with an even greater discrepancy between these relative rankings if “Economic” and “Strategic” criteria were combined into one same category), reflects the overriding economic discourse that appears to drive much decision making in the

region. Burton previously noted that "(high income countries) have generally assumed that they have the financial and technical resources to adapt as and when necessary" [42] suggesting that operational considerations are rarely the primary obstacles in decision making which is in marked contrast to discussions held with local stakeholders in BF.

The narrowest weight span was found for the "Animal and Environmental Health" category in BF suggesting stronger consensus among stakeholders as to the reduced importance of this category for them relative to all other categories. While the "Animal and Environmental Health" category was also among the bottom three weighted categories in QC, there was more dispersion in the weights given to this category suggesting that there was less of a consensus as to the relative importance of this category for QC stakeholders.

Effect on disease prioritization

Burkina Faso (BF) and the province of Quebec (QC) are very different regions on a multitude of levels. Notably, with regards to mortality, the leading cause of which is infectious diseases in BF whereas in QC, the greatest burden of disease across all ages is primarily due to non-communicable diseases. Based on the weights expressed by stakeholders, and region specific data assessments of the pilot diseases, some differences were found between the two regions in the ranked importance of these diseases.

In QC, the only disease currently occurring endemically is WNV and likely explains its first place ranking for this region. Among the remaining diseases, while MAL and DENV may be similarly of concern with regards to health severity, the current existence of suitable vectors for MAL in QC likely explains its higher ranking over DENV for this region. Suitable vectors (Aedes albopictus and Aedes aegypti) for CHIKV and DENV exist in the United States [43] but are not yet

present in Canada. There are concerns of these vectors making their way to Canada with continued climate change [44]. Malaria has historical transmission in Canada and the US prior to eradication efforts in the early 20th C and therefore suitable transmission conditions exist (i.e. vector and climate); however, studies examining chances of autochthonous transmission of this disease in Canada estimate that the risk is low given the disease transmission cycle requirements of this parasitic disease and current healthcare system [45]. While the combination of factors required for emergence and transmission of diseases is complex, the chances of a viral disease outbreak are generally considered to be higher once suitable vectors become present as replication times and requirements are generally shorter and simpler than for parasitic diseases [46]. Recent viral outbreaks in the United Kingdom would appear to support this [47]. CHIKV and LF have lower health severity and once again, the existence of effective treatment for LF is likely a driving cause of its last place ranking (hence lower concern).

In BF, DENV was ranked first among the five diseases according to the group ranking followed by MAL, CHIKV, LF and WNV respectively. The assessments for DENV and MAL differed primarily on the following criteria: “current incidence of human cases in the country” (currently unknown in the case of DENV), public perception and knowledge (relatively lower for DENV than for MAL currently in BF), “current global trend of disease over last 5 years” (MAL has been generally stable in the region),incidence and severity of animal disease (not applicable to MAL), cost to government and NGOs (more investment currently made for MAL hence costs higher), detection and treatment (treatment exists for MAL though a potential DENV vaccine may soon become available [48]). Furthermore, stakeholder weighting of criteria likely played an important role in the final group ranking of DENV above MAL. DENV outbreaks have occurred in BF (most recently in 2013 [49]) but current exact incidence and prevalence numbers are incomplete. Although MAL is the leading cause of death among infectious

diseases in BF, there is growing concern about underreporting and detection of DENV and greater attention to this disease is warranted [49]. While CHIKV may be present in BF, its lesser health severity compared with DENV and malaria likely play the largest part in reducing its priority order for this region. LF has long been present in the region, but also has lower health severity and effective treatment available. WNV has lower health severity assessment compared to the other four diseases and is likely the primary reason for its last place ranking.

Limitations

The list of criteria elaborated with stakeholders was based on an initial review of the literature by the authors and would likely have differed if criteria had been solely identified by stakeholders. However, in the interest of working towards a "complete" list of criteria, the participatory approach with stakeholders following the creation of an initial literature based set, allowed stakeholders to complete and give their opinion on criteria that have been used elsewhere resulting in an arguably more complete list than would have otherwise been created. The weighting exercise appeared to be challenging for some stakeholders and yet fairly intuitive for others, as such it would be worth looking into alternative ways of eliciting weights and adapting the use of these methods depending on the context and comfort of stakeholders. Alternative approaches have been used in other studies including discrete choice experiment approaches [50] such as conjoint analysis [26] and consensus methods and may be worth exploring in future studies. With regards to the pilot prioritization, this was aimed at illustrating the effect of different criteria and weights on disease ranking and should not be interpreted as a formal assessment of local priorities. Data from the literature and to some extent, from preliminary discussions with stakeholders was used to score diseases. Additional data as well as further discussion with experts and stakeholders is warranted to verify the validity of these findings.

Conclusions

Common categories and criteria of concern can be found among stakeholders in low- and middle-income countries versus high income contexts. While global concerns may be similar, subtle differences exist that reflect local realities and priorities. These nuances with regards to the relative importance of certain categories versus others can offer much insight into health care conditions, and operational capacity in different contexts. Notably, the apparent lack of decision making autonomy of local stakeholders in low- and middle-income countries contexts stands out as very important factor affecting decision-making in these contexts. Global burden of disease studies remain important for assessing the status of current global health, examining potential disparities and evaluating progress over time. Cost-effectiveness studies also play an important role in attempting to maximize health gains per dollar spent. However, with regards to priority setting, these approaches may not be sufficient to take in local concerns. A more holistic and rigorous approach is necessary to investigate whether local concerns line up with international or external concerns and examine how different or similar resulting priorities may be in order to improve eventual buy-in and efficiency of interventions.

Although the broad considerations for prioritization of disease impact appear consistent across different regions and socio-economic contexts, the resulting priorities are not universal (one size fits all). Priorities should be driven by context specific information to reflect local realities. Participatory decision aid approaches provide opportunities for rich dialogue and knowledge exchange between stakeholders with regards to the numerous dimensions of concern surrounding climate sensitive infectious disease prioritization and management. Furthermore, given the vast number of actors in low- and middle-income countries settings, multi-actor collaborations across NGOs, local government and community are important and formal decision aid approaches offer an

opportunity to align or address conflicts or divergent priorities, contributing to eventual consensus building and improved buy-in of all stakeholders in resulting priorities. Participatory, multi-stakeholder approaches also provide a systematic traceability for improved understanding of why one disease might be perceived as more important than another.

The pilot prioritization rankings presented in the current study should not be used as a prescriptive tool, but rather, this exercise should be seen as an opportunity to explore, align and address varied stakeholder interests. Participatory decision aid approaches allow us to be explicit and transparent about what we think is most important, and distance and detach the effect of these value-laden considerations to examine their effects on disease rankings. Although decision aid approaches such has MCDA are far from being a magic bullet to the legacy of development aid related concerns in low- and middle-income countries, they may offer a helpful approach to investigating potential alignment discrepancies between the concerns of external donors and local stakeholders as well as offer an opportunity to build shared understanding and buy-in of proposed paths forward.

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Author Contributions

VH and CC carried out the focus group discussions in QC. VH, KS and HC carried out focus groups discussion in BF. VH performed the analyses and wrote the manuscript. PM, PG, CC, KS, HC, AR, and JPW contributed to analysis and interpretation of the data and writing of the manuscript. All authors read and approved the final version of the manuscript.

Conflicts of interest

All authors declare that they have no conflicts of interest.

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CHAPTER 4

KNOWLEDGE AND PROTECTIVE MEASURES ADOPTED BY QUEBEC RESIDENTS AGAINST MOSQUITOES AND WEST NILE VIRUS[3]

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Abstract

Recent case numbers of West Nile virus (WNV) have been low in the province of Quebec; however, spikes in incidence have occurred since it first emerged in 2002. While the majority of cases of WNV are asymptomatic, a small number result in more severe complications including death. Recommended preventive measures, including individual behaviours, are thought to be effective at reducing the risk of West Nile virus. Given ongoing concern for WNV here in Canada and global resurgence of mosquito-borne arboviruses such as Zika, there is a need to periodically examine the current state of awareness and adoption of preventive behaviours against mosquito bites in the population. Additionally, given regional differences in recent case occurrence, we examined differences in knowledge, perceptions and behaviours between two at-risk regions in Southern Quebec.

A web-based survey was administered to southern Quebec residents to assess knowledge, perceptions and adoption of recommended preventive measures against mosquitoes and WNV. Overall reported awareness (90%), knowledge of WNV transmission (76%) and practice of recommended preventive measures (85% report habitual use) was good among respondents. However, concern and perceived severity appear to have decreased since a 2004 provincial survey. No significant differences in knowledge and behaviour were found between the two examined risk regions, though some differences in perceived exposure were found. Based on an exploratory multiple correspondence analysis of all sampled respondents, four distinct groups of respondents were found. While a majority (two out of four groups) of respondents report good adoption of preventive measures, a small group were unaware of and had poor knowledge of WNV, though perceive less exposure to mosquitoes. A fourth group was found with good knowledge of WNV yet low concern and low adoption levels of recommended preventive measures compared to the first two groups.

These results suggest that while awareness of WNV and adoption of recommended preventive measures is generally good in the study population, motivation to adopt preventive measures is not uniform. Awareness remains paramount in cueing good preventive behaviours. Ongoing vector-borne disease education, including the existence of vector-borne diseases of concern and where disease risk regions exist in the province, will be key to reducing vector-borne and WNV risk in the future. WNV and other vector-borne disease risk regions vary in space and time in the province, therefore, it is important for public health to continue to monitor changing perceptions and behaviours as well as disease incidence in the region so that targeted messages can be sent to target populations and high risk areas at key times. This study offers insights into groups to further study and target for vector-borne disease education and awareness campaigns.

Introduction

Over the last few decades, there has been a global resurgence of mosquito-borne arboviruses such as WNV, dengue, Chikungunya, Zika virus and Yellow fever with the latter two being the most recent to cause epidemics of global concern (1–3). This resurgence of arboviruses serves as a reminder to regularly assess the population level of awareness and adoption of recommended preventive measures (RPM) against mosquitoes and mosquito-borne disease. While dengue, Chikungunya, Zika and Yellow fever do not currently circulate in Canada, WNV has been endemic in the country since 2001 and in southern parts of the province of Quebec since 2002 (4–6).

WNV is a flavivirus whose symptoms are primarily asymptomatic with one quarter exhibiting febrile symptoms and 1% resulting in more severe neurological symptoms or death (7). In Quebec, 37 human cases of WNV were recorded in the first 2 years following the disease's appearance in the province (8). Fewer than 20 cases were recorded over the next seven years until a resurgence of the virus in 2011 when 42 cases occurred and 134 cases

were recorded in 2012 (8). At the time of its emergence in 2002, WNV dominated news headlines and was a Public Health and research priority. Despite the 2012 spike, cases remained relatively low in Quebec following this with only 32, 6, 45 and 30 cases recorded respectively in the province in the four years after the spike, and 9 deaths recorded since 2012 (8).

Recommended preventive measures (RPMs) in Canada (and the province of Quebec) are targeted at avoiding mosquito bites via the use of long sleeved clothing when outdoors (especially during peak mosquito activity), use of insect repellents (containing DEET, Icaridin or biopesticides), use of mosquito screens on doors and windows, as well as reducing the number of mosquitoes in one's environment by eliminating stagnant water, and draining, covering or changing water in outdoor containers (9–11). A number of communication campaigns and assessments of population awareness of WNV and mosquito preventive behaviours have been carried out over the years since the disease's emergence in North America (12–27). The use of personal preventive measures and environmental source reduction measures (e.g. draining or changing standing water) are estimated to be effective means of reducing illness caused by mosquito-borne diseases such as WNV (6,28).

Evaluations of knowledge, beliefs and behaviours (17,23,27,29), at times within explicit health belief model (HBM) frameworks (12,14,21,26,29), have been widely used to help identify factors that relate to the adoption of RPMs. The HBM is a theoretical model that was developed to help understand individuals' intended adoption of preventive health behaviours based on various perception variables such as the individual's perceived severity of a disease, perceived susceptibility to the disease, perceived barriers and benefits to adopting preventive behaviours, cues to action, knowledge about the disease and socio-demographic factors (30). Knowledge and awareness about a disease or health condition are deemed important factors in motivating an individual's intention to adopt appropriate health behaviours,

though they have often been found insufficient on their own to explain RPM use (15–17,22,23). Other beliefs present in the HBM framework (31) such as perceived susceptibility and severity of WNV, perceived benefits and barriers to RPM use and sociodemographic factors have also been correlated with intended adoption of RPMs with increased levels of concern generally associated with an increased propensity to adopt an appropriate RPM (12,15,18,21).

Periodic assessments of population awareness and behaviours in Quebec reveal that awareness about WNV has generally increased since the disease first emerged in 2002, and while reported RPM use has also increased compared with evaluations done pre-emergence in the province (31), reported RPM use levels have not changed much in the 15 years since. Early 2003 provincial assessments reported 60% use of either mosquito sprays, long sleeved clothing, screens or source reduction of stagnant water (32). Focus group assessments also held in 2003 revealed that most study participants had heard of the disease but that transmission knowledge was low (27). Concern for WNV was also low. Preventive behaviour was generally motivated by the perceived presence of nuisance mosquitoes around the home with the most common strategy adopted being the avoidance of mosquitoes in the first place. Reported window and door screens use was ubiquitous among participants. A 2004 provincial assessment found that awareness of WNV was generally lower among language minorities in Quebec, low income households (under 15,000$), those with only primary and secondary education and those above 65; however, risk perception of the disease was generally found to be higher among Anglophones (33). Overall study results were found to be similar to other pan-Canadian and American surveys done around that time showing that reported awareness was generally high, knowledge of symptoms was often incomplete and concern about the disease was generally low among compared studies (33). Earlier Canadian surveys had found awareness of WNV to be around 70% and the adoption of at least one

preventive measure to be around the same level in assessed populations (24,26). A 2004 regional study in Quebec found a very high awareness of WNV among respondents (96%) accompanied by a high knowledge of its transmission (90% gave an acceptable response) (20). A majority (80%) of participants surveyed perceived the risk of becoming infected with WNV to be low and close to 60% perceived the severity of a potential infection to be high or very high (20). Reported repellent use was 47% and the reported use of protective clothing was 57%. A 2013 assessment in the year following the 2012 outbreak, found that 70% of Montreal metropolitan residents knew that WNV was transmitted by mosquitoes; however, risk perception had reportedly decreased (34). One third of respondents reported using long sleeved clothing and 50% reported the use of insect repellent to protect themselves from mosquito bites.

Given ongoing fluctuations in WNV case numbers in Quebec and anticipated increase in suitable climate for transmission under climate change (35), it is of interest to examine the current state of knowledge, perceptions and behaviours of the population with respect to mosquitoes and WNV in order to make more informed prevention and control decisions. We examined current knowledge and awareness of WNV, perceived exposure to mosquitoes and reported adoption of RPMs by means of an online population survey. We explored the potential relationship between these variables within our sample population by means of a multiple correspondence analysis (MCA). Additionally, given the higher number of cases and deaths from WNV having occurred in the greater Montreal area (Laval and Montérégie regions included), comparisons were made between this region and other targeted regions of the province to see whether knowledge levels, perceptions or behaviours differed between regions of the province that might explain some of the observed differences in cases.

Methods

A cross-sectional survey was designed to assess knowledge, perceptions and adoption of recommended preventive measures (RPMs) against mosquitoes, and WNV among English and French speaking residents of southern Quebec (Canada). Based on planned WNV surveillance locations by the province and conscious of budget constraints (36), seven regions were sampled. These regions included Montreal, Montérégie, Laval, Lanaudière, Laurentians, Outaouais, and the Quebec City region (Fig. 4) and represented close to 75% of the Quebec population in 2015 (37).

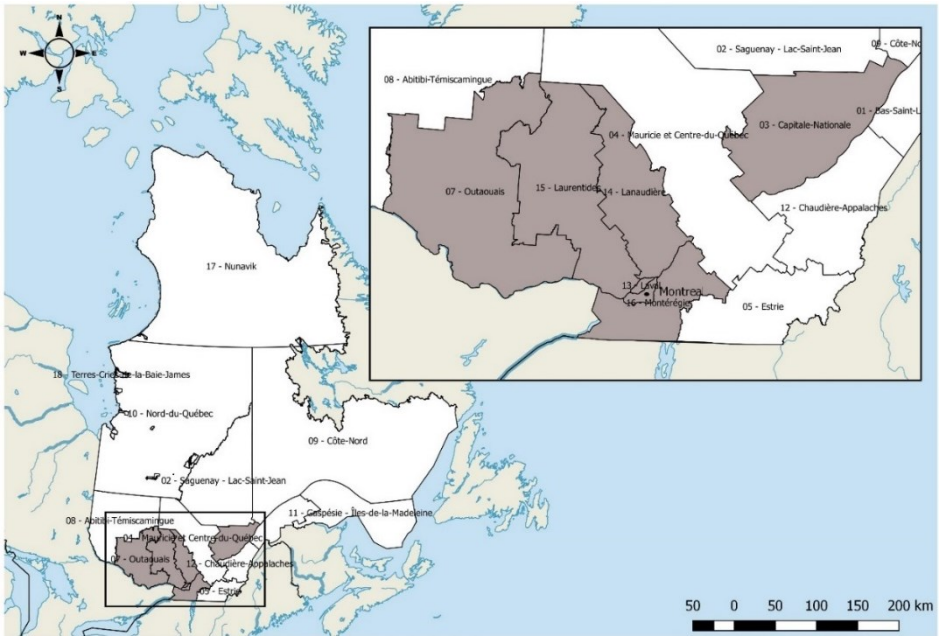

Figure 4. Map of administrative regions of Quebec

Survey administration and study population

An online survey was administered by survey firm Leger Marketing to a pre-existing web panel which they maintain (38). The Legerweb panel consists of individuals and households that have been recruited by random digit dialing invitations and voluntary sign-up and whose members have agreed to participate in phone, mail and internet-survey research. The panel contains over 400,000 members in Canada and was designed to be socio-demographically representative of Canadians. Panelists can receive online-

rewards (generally one dollar) per survey completed in exchange for providing accurate socio-demographic profiles of themselves. Invitations to participate in the current study were sent by Leger Marketing to 7416 panelists between 27 May and 5 June 2016. Survey participants had to consent to participate in the survey, be 18 years of age or older, and reside in one of the seven study regions (Fig 4). Individuals not meeting the previous criteria resulted in incomplete surveys. Respondents had the choice of completing the survey in either English or French.

In order to test for differences in knowledge, perceptions or behaviours between areas where WNV deaths have occurred in the last 5 years prior to this survey, the study population was divided into two risk regions (Table XIII). Risk region 1 (RR1) has reported more cases and deaths due WNV than risk region 2 (RR2). Based on a desire to detect a 10% difference between the regions, a reported RPM use estimated around 50% in RR1, a power of 80% and 95% confidence level, a minimum of 400 participants were selected from each of the two risk regions.

The protocol for this project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (Comité d'éthique de la recherche en santé, CERES) (certificate number 14-025-CERES-D). All participants gave informed consent by clicking a checkbox within the electronic survey for inclusion prior to participation in the study.

Table XIII. 2011-2015 Cases and deaths (in parentheses) of West Nile virus by region

Region	2015	2014	2013	2012	2011
Risk Region 1					
Montérégie	16	3	14	42 (2)	15
Montréal	8	2	4 (1)	36 (2)	13
Laval	11 (1)		5	24 (1)	5
Risk Region 2					
Laurentians			4	18	4
Lanaudière	5	1	1	5	
Outaouais	1		1	4	5
QC City region	1		1	2	
Total for both regions	42 (1)	6	30 (1)	131 (5)	42
Yearly incidence †					
Risk Region 1	0.89	0.13	0.58	2.59	0.84
Risk Region 2	0.32	0.05	0.32	1.31	0.41

† per 100,000 based on 2015 estimated population numbers from the Quebec Institute of Statistics (37)
West Nile virus case data source: Health and Social Services of Quebec (8)

Survey description

A questionnaire was designed based on previous questionnaires administered in Quebec (20,32–34) and on WNV (12,14,15,18,20,21,26,29) to capture data on knowledge, perceptions and behaviours of the population with respect to mosquitoes and WNV. Questions on WNV disease awareness, perceived susceptibility, perceived severity, perceived self-efficacy, cues to action, perceived benefits, perceived barriers and adoption of recommended preventive measures, as derived from previous studies in Canada and the USA (12,14,15,18,20,21,26,29) were included. A ten-point scale was used for perceived self-efficacy and perceived severity with participant responses recoded to low (1-3), medium (4-7), high (8-10). Five-point Likert scales were used for behaviour and remaining perception questions. Following up on work by Trumbo & Harper (12) and Zielinski-Gutierrez (39), elements of affective (worry or anxiety) and cognitive risk perception, perceived mosquito exposure (i.e. report seeing or bitten by mosquitoes and problem perception of mosquitoes) and proximal exposure (measured via garden access and visits to forested areas) were also included to capture ecological and proximal measures of risk. In lieu of cognitive risk related questions, a WNV knowledge score was calculated based on the number of correct responses to questions pertaining to WNV transmission, symptoms, vulnerable groups and treatment (maximum score of 4). Additionally, in the study by Gujral et al. (2007), a question was raised as to whether or not residents from a comparison group that had experienced higher levels of neuroinvasive WNV had chosen to rely on city control rather than practicing individual measures to protect themselves (18). As a result, questions in our survey concerning perceived responsibility versus public health responsibility to take action to protect oneself from mosquito exposure were also included.

Socioeconomic and demographic information including age, gender, education and household income were also collected along with the number of children under 18 years of age living in the household. A pilot survey of 32

individuals (12 English and 20 French) was conducted to ensure clarity of questions prior to administration of the final survey by Leger Marketing.

Data analysis

The proportion of responses by risk region, age, sex and language were recorded. Statistical analyses were conducted using R (version 3.3.1) (R Core Team (2016), Vienna, Austria, https://www.r-project.org/). Confidence intervals for proportions were calculated using the Agresti-Coull method with 95% confidence level. Pearson Chi-square tests were used to assess differences between regions. An exploratory multiple correspondence analysis (MCA) (40) was conducted using the FactoMineR package in R (http://factominer.free.fr/) on the socio-economic, and adapted HBM framework variables (perceived severity, perceived susceptibility, cues to action, perceived self-efficacy, perceived benefits, perceived barriers, perceived responsibility, perceived exposure, and ecological proximity). To see whether distinct subgroups of respondents might exist within the data and for insight into patterns of RPM adoption, a hierarchical cluster analysis was performed on the principal components identified in the MCA analysis. This was done with the FactoMineR package which uses chi-square distance for categorical data clustering, the Ward criterion for agglomeration and partitional clustering with Q clusters and a k-means algorithm (40). Individuals are clustered based on similarity of responses to variables associated with the cluster as compared to individuals outside of the cluster. The perceived severity, perceived benefits, perceived barriers, perceived exposure (seeing or bitten by mosquitoes), perceived responsibility to protect (self or public health authority), and adopted RPM variables (wearing protective clothing, using DEET and source reduction of standing water) were dichotomized (0 or 1) so as to consider only the highest levels of each variable and facilitate visual interpretation and analysis.

Results

In response to the online survey, 1039 individuals accepted to participate (response rate of 14%). A total of 804 respondents met the inclusion criteria (living in one of the seven identified regions, 18 years of age or older and speaking English or French). An overview of respondent demographics is shown in Table XIV.

Table XIV. Demographic overview of survey respondents

	Risk Region 1		Risk Region 2	
	N=404	%	N=400	%
Gender				
Women	207	51.24	192	48.00
Men	197	48.76	208	52.00
Survey Language				
French	264	65.35	364	91.00
English	140	34.65	36	9.00
Mother tongue				
French	238	58.91	350	87.50
English	100	24.75	40	10.00
Other	66	16.34	10	2.50
Age				
18-34 yrs.	98	24.26	105	26.25
35-54 yrs.	160	39.60	158	39.50
55+ yrs.	146	36.14	137	34.25
Education Level				
High school or less	87	21.53	90	22.50
College or equivalent	138	34.16	165	41.25
University or equivalent	179	23.27	144	18.50
N/A±	0	0.00	1	0.25
Household income ($CAN)				
<40 000	87	21.53	74	18.50
40 000 - 99 999	193	47.77	200	50.00
> or = 100 000	73	18.07	84	21.00
N/A±	51	12.62	42	10.50

± Prefer not to answer

The study sample was found to be similar to the general population of Quebec with regards to age, sex and education levels (41,42). The proportion of respondents reporting 'French' as their mother tongue was similar though slightly lower to 2011 census data for the province of Quebec, while the proportion of respondents reporting 'English' was slightly higher and the proportion of respondents who answered 'other' was slightly lower (43). With regards to income, the proportion of respondents making over 40,000$ was similar compared to statistics available for the province of Quebec, however the proportion of respondents making less than 40,000$ was under

represented in our sample (2011 statistics indicated 26.9% making 20,000-40,000$ and 13.6% making less than 20,000$) (44). Survey completion took an average of 15 mins with a majority of participants, 628 (78.1%) responding in French.

Knowledge, perceptions and behaviour

Mosquito and WNV knowledge, perception and behaviour responses are shown in Table XV. Awareness of WNV was good with 722 (90% overall; 93% in RR2 vs 87% in RR1, p=0.003) participants having previously heard of WNV. Lyme disease was incorrectly identified by 418 (52%) participants. WNV transmission knowledge was good with 616 (77%) participants able to correctly identify the bite of an infected mosquito as the mode of transmission; however, only 396 (49.3% overall; 54% in RR2 vs 45% in RR1, p=0.011) participants identified WNV as being one of the diseases currently transmissible by mosquitoes in Quebec. Tick bite transmission was incorrectly identified as a mode of WNV transmission by 191 (24%) participants. WNV symptom knowledge varied with 444 (55%) participants correctly identifying flu-like symptoms; however, 114 (14%) participants incorrectly identified a bull's eye rash as a symptom. Knowledge of WNV vulnerable groups was low with 225 (28%) correctly identifying older adults (55 years and up) as most vulnerable. Treatment responses varied with 289 (36%) responding hospital care, however, 238 (30%) believed antibiotics could be used to treat WNV.

Knowledge scores were similar among the three age groups (18-34; 34-55; 55+); however, among respondents aged 55 years and older, only 60 (21%) knew that their age group was most vulnerable to WNV. The top five health information sources cited among all respondents included internet (63%), television (56%), newspapers (41%), radio (30%) and family physicians (26%) the latter of which was significantly higher in RR2 (32% vs 21% in RR1, p=0.001). However, only 324 (40%) participants recalled having heard about WNV the previous summer.

Mosquitoes were perceived by 621 (77%) participants to be a nuisance. Perceived exposure to mosquitoes varied among respondents with more from RR2 reporting seeing (62% RR2 vs 46% RR1, p<0.01) or being bitten (37% RR2 vs 24% RR1, p<0.01) often by mosquitoes. Most participants, 717 (89%), perceived a benefit to adopting preventive measures against mosquitoes and 528 (66%) perceived themselves as having medium-high personal control over mosquito-borne disease risk. Disease severity was perceived to be moderate as indicated by 474 (59%) participants. Only 108 (13%) participants (agree or strongly agree) perceived themselves to be susceptible to WNV.

Screen use was widespread with 683 (91%) participants reporting habitual ('usually' or 'always') use. The practice of the remaining RPMs, wearing protective clothing, using repellent containing DEET, draining or changing standing water outdoors, was also good with 568 (71%) participants reporting habitual adoption of at least one these measures (Fig 5).

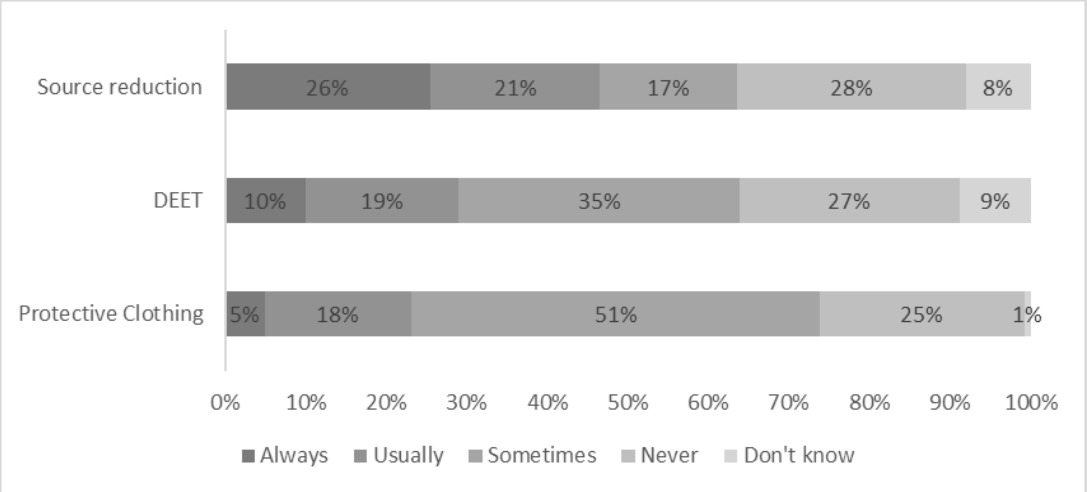

Figure 5. Reported adoption of preventive measures by participants

Table XV. Region specific responses to Knowledge, Perception and Behaviour questions

	Risk Region 1 (n=404)			Risk Region 2 (n=400)		
	n	%	CI[1]	n	%	CI[1]
Knowledge						
Heard of WNV prior to survey	350	86.6	(83-90)	372	93.0	(90-95)*
Known WNV transmitted by infected mosquito	304	75.2	(71-79)	312	78.0	(74-82)
Have no symptom knowledge	168	41.6	(37-46)	159	39.8	(35-45)
Know older adults (55+) most vulnerable to WNV	108	26.7	(23-31)	117	29.3	(25-34)
Treatment by hospital care	146	36.1	(32-41)	143	35.8	(31-41)
WNV knowledge score = 0 †	100	24.8	(21-29)	88	22.0	(18-26)
WNV knowledge score medium (1or2) †	204	50.5	(46-55)	213	53.3	(48-58)
WNV knowledge score high (>2) †	100	24.8	(21-29)	99	24.8	(21-29)
Perceptions						
Perceived exposure – see mosquitoes often	184	45.5	(41-50)	249	62.2	(57-67)*
Perceived exposure – bitten mosquitoes often	98	24.2	(20-29)	148	37.0	(32-42)*
Express low personal control over mosquito-disease	121	30.0	(26-35)	155	38.8	(34-44)*
Express medium Personal control over mosquito-disease	216	53.5	(49-58)	236	59.0	(54-64)
Express high Personal control over mosquito-disease	56	13.9	(11-18)	33	8.3	(6-11)*
Perceived themselves as susceptible to WNV if no RPM	53	13.1	(10-17)	55	13.8	(11-17)
Perceive risk of WNV to Quebecers moderate or high	163	40.3	(36-45)	149	37.3	(33-42)
Perceive WNV severity as low	41	10.1	(7-14)	55	13.8	(11-17)
Perceive WNV severity as medium	223	55.2	(50-60)	251	62.8	(58-67)*
Perceive WNV severity as high	102	25.2	(21-30)	72	18.0	(15-22)*
Perceive benefits to adopting RPMs	367	90.8	(88-93)	350	87.5	(84-90)
Perceive barriers to adopting RPMs	337	83.4	(79-86)	356	89.0	(87-92)*
Report no mosquito problem in neighbourhood	148	36.6	(32-41)	139	34.8	(30-40)
Report low mosquito problem in neighbourhood	190	47.0	(42-52)	195	48.8	(44-54)
Report medium-high mosquito problem in neighbourhood	66	16.3	(13-20)	66	16.5	(13-20)
Garden or terrace access and responsibility for upkeep	204	50.5	(46-55)	261	65.3	(60-70)*
Fewer than 2 visits to wooded areas last summer	150	37.1	(33-42)	104	26.0	(22-31)*
Perceive self responsibility to protect against WNV	260	64.4	(60-69)	261	65.3	(60-70)
Perceive PHA responsibility to protect against WNV	160	39.6	(35-44)	150	37.5	(33-42)
Behaviours						
Wears protective clothing ±	99	24.5	(21-29)	87	21.8	(18-26)
Uses DEET ±	108	26.7	(23-31)	125	31.3	(27-36)
Drains or changes standing water ±	231	57.2	(52-62)	229	57.3	(52-62)
Uses screens on windows and doors ±	362	89.6	(86-92)	366	91.5	(88-94)

[1]95% confidence intervals (Agresti-Coull method); * p<0.05 (Pearson Chi-square)
† based on knowledge of WNV transmission, symptoms, vulnerable group and treatment
± usually or always

Multiple correspondence analysis

An exploratory multiple correspondence analysis (MCA) was performed on the 744 (93%) individuals who had previously heard of WNV prior to the survey. Sixty individuals who responded that they had not heard of WNV prior to the survey were removed since these respondents had missing data. The first three dimensions in this analysis were found to explain 18.30%, 10.94% and 7.78% of the data respectively for a combined total of 37% of the inertia in the data. Figure 6 presents the spatial relationship of the variables most strongly associated with each of the three dimensions. Table XVI shows the top ten contributing variables to each of the dimensions. Perceived mosquito problem and concern about WNV were most strongly

associated with the 1st dimension while risk to self and others of contracting WNV, knowledge, and awareness of WNV (heard) were most strongly associated with the 2nd dimension. Perceived exposure (seeing or bitten by mosquitoes) and perceived benefits to RPM use were most strongly associated with the 3rd dimension.

Table XVI. Description of top 10 variables contributing most to each MCA dimension

Dimension 1			Dimension 2			Dimension 3		
Variable	R2	p.value	Variable	R2	p.value	Variable	R2	p.value
mpb	0.37	<0.01	RO	0.43	<0.01	bit	0.41	<0.01
anx	0.36	<0.01	RS	0.41	<0.01	see	0.30	<0.01
deet	0.24	<0.01	anx	0.29	<0.01	ben	0.13	<0.01
RS	0.24	<0.01	kwnv	0.22	<0.01	anx	0.14	<0.01
see	0.22	<0.01	AWv	0.19	<0.01	RS	0.13	<0.01
Rse	0.18	<0.01	ben	0.13	<0.01	mpb	0.12	<0.01
Rph	0.17	<0.01	bar	0.12	<0.01	Rse	0.10	<0.01
RO	0.17	<0.01	Rse	0.11	<0.01	sevh	0.08	<0.01
bit	0.15	<0.01	mpb	0.06	<0.01	Rph	0.08	<0.01
ben	0.12	<0.01	pch	0.04	<0.01	deet	0.08	<0.01

R2 : Correlation ratio between the variable and the coordinates of the individuals on the dimension;
Anx, anxiety or worry about WNV; AWv, aware of WNV prior to survey (heard); bar, perceived barriers to RPM use; ben, perceived benefits to RPM use; bit, perceived exposure (bitten by mosquitoes often); deet, uses deet usually or always; kwnv, WNV knowledge score; mpb, perceived mosquito problem; pch, perceived self-efficacy to protect self from mosquitoes; RO, perceived risk to others of WNV, Rph, Public health authority's responsibility to protect from WNV; RS, perceived risk to self of WNV; Rse, self responsibility to protect from WNV; see, perceived exposure (see mosquitoes often); sev, perceived severity of WNV.

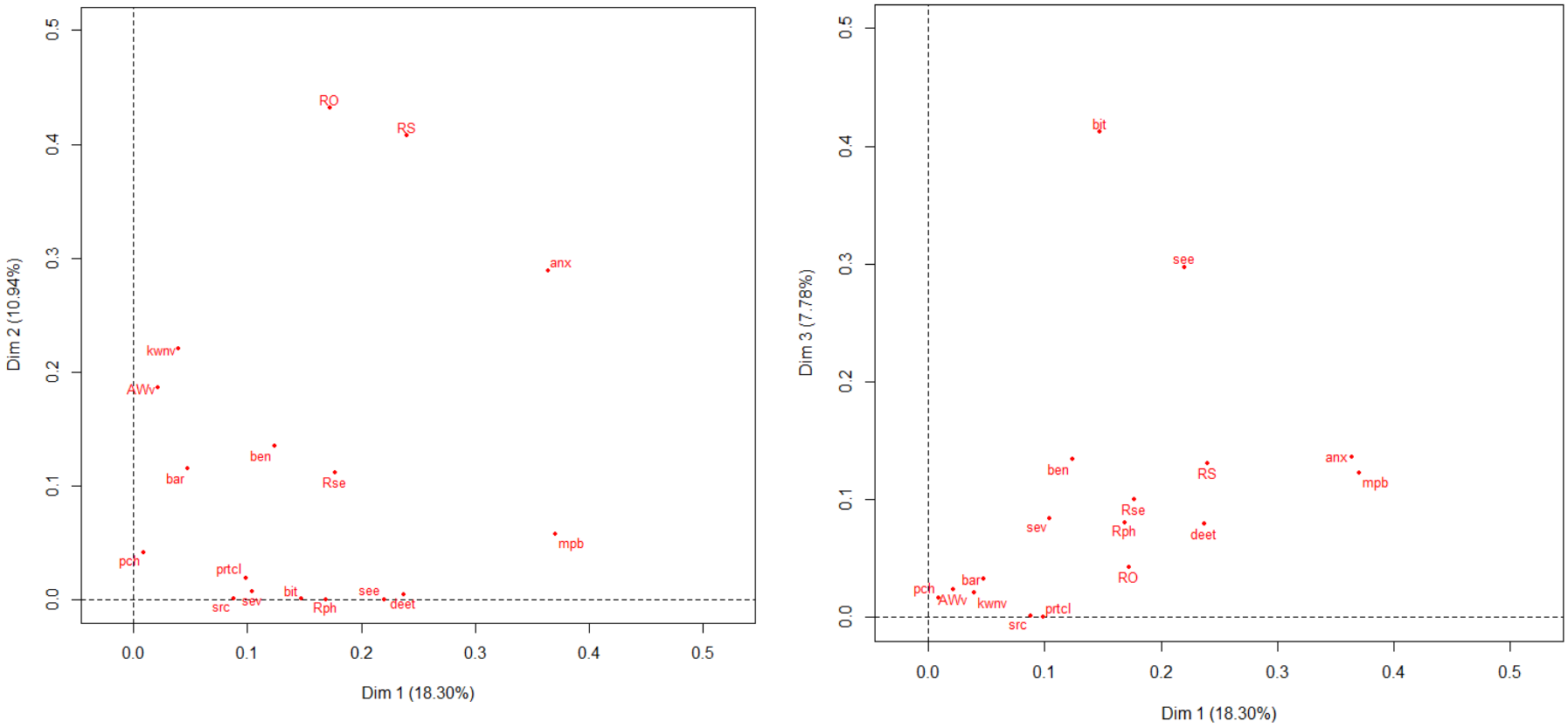

Figure 6. Relationship among variables and the dimensions in the MCA analysis.

Variables further along the horizontal-axis (e.g. mpb, mosquito problem perception) are more strongly associated with Dimension 1. Variables further along the vertical-axis are more strongly associated with Dimensions 2 (left graph – e.g. RO, perceived risk to others of WNv) and 3 (right graph – e.g. bit, perceived exposure to mosquito bites).

Anx, anxiety or worry about WNv; AWv, aware of WNv prior to survey (heard); bar, perceived barriers to RPM use; ben, perceived benefits to RPM use; bit, perceived exposure (bitten by mosquitoes often); deet, uses deet usually or always; kwnv, WNv knowledge score; mpb, perceived mosquito problem; pch, perceived self-efficacy to protect self from mosquitoes; prtcl, wears protective clothing usually or always; RO, perceived risk to others of WNv, Rph, Public health authority's responsibility to protect from WNv; RS, perceived risk to self of WNv; Rse, self responsibility to protect from WNv; see, perceived exposure (see mosquitoes often); sev, perceived severity of WNv.

Next, a hierarchical cluster analysis was performed to detect patterns among the sample of respondents (Fig. 7). Variables most strongly associated with each of the clusters are shown in Table XVII. The 1st cluster was characterized by individuals who were aware of WNV, but were not concerned about it, did not consider themselves at risk, perceived no mosquito problem where they lived, considered the risk to Quebecers of contracting WNV to be low, did not think it was their responsibility to protect themselves from WNV, and were not homogeneous in the number of RPMs adopted but generally practiced few RPMs. There was a larger concentration of individuals from the Quebec City capital region within this cluster. The 2nd cluster was characterized by individuals who were generally unaware of WNV, had poor knowledge scores for WNV, had little exposure to mosquitoes, had neutral concern about their risk of contracting WNV, did not think it was their responsibility to protect themselves from WNV, and responded that they did not know whether WNV was a risk to Quebecers or not. This group of individuals tended to have more individuals from the Montreal region, have a high school education, less access to gardens and travelled to wooded areas less than twice per year. The 3rd cluster perceived mosquitoes to be a minor problem, had good knowledge scores for WNV, had moderate concern about WNV, generally perceived the risk of WNV to Quebecers to be moderate, perceived it to be their responsibility to protect themselves from mosquitoes, had higher perceived exposure to mosquitoes than cluster 1 and 2, and generally practiced more RPMs than the previous two clusters as well. The 4th cluster was the most concerned about WNV out of the four clusters, had good knowledge scores for WNV, had higher perceived exposure to mosquitoes (saw and were bitten by mosquitoes often), perceived the severity of WNV to be high, perceived it to be their responsibility to protect themselves from mosquitoes and were more concerned about the risk of WNV to Quebecers than clusters 2 and 3. This group tended to practice more RPMs than clusters 1 and 2.

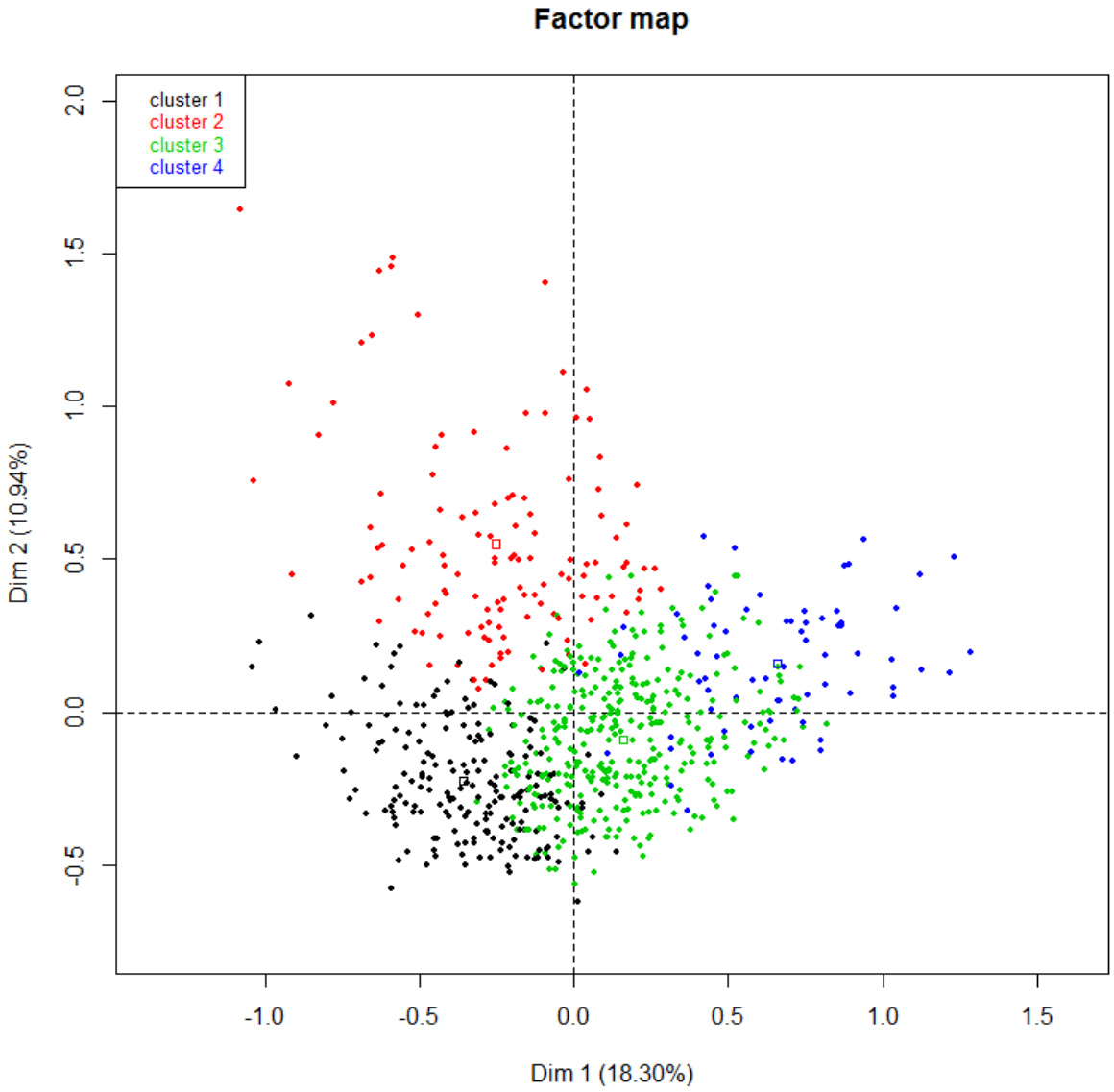

Figure 7. Results of MCA and hierarchical cluster analysis for respondents.
Four clusters are shown with members colored by cluster membership (black, red, green and blue) suggesting that individuals primarily contained in the upper left quadrant are most similar in their response patterns compared to individuals outside this cluster and are primarily members of cluster 2 (colored in red); individuals in the lower left quadrant are primarily members of cluster 1 (colored in black); individuals in the lower right quadrant are primarily members of cluster 3 (colored in green) and individuals in the upper right quadrant are a mix of members of clusters 2,3 and 4 with members of cluster 4 (colored in blue) appearing primarily at the right extremity of this quadrant. Variables associated with each of the four clusters are described in Table XVII.

Table XVII. Top fifteen contributing variables and response categories for each cluster

Cluster 1 (n=197)						Cluster 2 (n=113)					
Variable	**Cl/Mod**	**Mod/Cl**	**Glob**	**p.val**	**v.test**	**Var**	**Cl/Mod**	**Mod/Cl**	**Glob**	**p.val**	**v.test**
anx=1	70.54	78.61	30.11	<0.01	17.26	RS=3	41.20	79.34	31.32	<0.01	12.00
RS=1	78.29	50.25	17.34	<0.01	13.62	RO=-1	96.77	24.79	4.17	<0.01	10.19
mpb=0	55.60	74.13	36.02	<0.01	13.06	Rse=0	37.22	68.60	29.97	<0.01	9.66
RO=1	39.64	77.11	52.55	<0.01	8.32	ben=0	55.00	36.36	10.75	<0.01	8.56
Rph=0	35.94	77.61	58.33	<0.01	6.64	kwnv=0	44.53	47.11	17.20	<0.01	8.56
see=0	38.48	65.67	46.10	<0.01	6.52	anx=3	37.91	57.02	24.46	<0.01	8.48
q0qc=QC	55.79	26.37	12.77	<0.01	6.36	AWv=N	95.45	17.36	2.96	<0.01	8.29
deet=0	32.83	86.07	70.83	<0.01	5.80	bar=0	42.16	35.54	13.71	<0.01	6.82
prtcl=0	31.35	89.05	76.75	<0.01	5.07	Rph=0	21.20	76.03	58.33	<0.01	4.41
Rse=0	39.91	44.28	29.97	<0.01	5.06	educ3=HS	24.84	33.06	21.64	<0.01	3.19
sevh=0	31.05	88.06	76.61	<0.01	4.68	inc4=0-39k	24.82	28.93	18.95	<0.01	2.92
src=0	35.20	53.23	40.86	<0.01	4.14	deet=0	18.60	80.99	70.83	0.01	2.75
bit=0	30.96	80.10	69.89	<0.01	3.77	src=0	20.72	52.07	40.86	0.01	2.71
sexe=Ma	32.89	61.19	50.27	<0.01	3.63	q0qc=MTL	21.86	33.06	24.60	0.02	2.30
langu=Fr	30.35	82.59	73.52	<0.01	3.49	q0qc=LAU	24.73	19.01	12.50	0.02	2.25
Cluster 3 (n=370)						**Cluster 4 (n=64)**					
Variable	**Cl/Mod**	**Mod/Cl**	**Glob**	**p.val**	**v.test**	**Variable**	**Cl/Mod**	**Mod/Cl**	**Glob**	**p.val**	**v.test**
mpb=l	67.68	69.41	48.66	<0.01	10.87	anx=5	100.00	30.43	2.82	<0.01	10.05
Rse=1	59.88	88.39	70.03	<0.01	10.68	mpb=h	78.57	31.88	3.76	<0.01	9.04
ben=1	52.71	99.15	89.25	<0.01	9.12	RS=5	93.75	21.74	2.15	<0.01	8.02
anx=2	68.64	42.78	29.57	<0.01	7.53	sevh=1	24.14	60.87	23.39	<0.01	7.02
RS=2	61.31	47.59	36.83	<0.01	5.78	RO=3	46.51	28.99	5.78	<0.01	6.65
Rph=1	59.03	51.84	41.67	<0.01	5.35	Rph=1	17.10	76.81	41.67	<0.01	6.19
RO=2	60.08	43.06	34.01	<0.01	4.95	deet=1	18.43	57.97	29.17	<0.01	5.22
q0qc=OUT	70.10	19.26	13.04	<0.01	4.80	anx=4	25.77	36.23	13.04	<0.01	5.20
see=1	55.36	62.89	53.90	<0.01	4.68	mpb=m	26.74	33.33	11.56	<0.01	5.09
bar=1	50.62	92.07	86.29	<0.01	4.40	bit=1	16.96	55.07	30.11	<0.01	4.52
AWv=Y	48.75	99.72	97.04	<0.01	4.37	see=1	13.47	78.26	53.90	<0.01	4.36
src=1	54.09	67.42	59.14	<0.01	4.37	prtcl=1	16.76	42.03	23.25	<0.01	3.63
RS=4	67.39	17.56	12.37	<0.01	4.09	langu=O	21.88	20.29	8.60	<0.01	3.19
anx=4	65.98	18.13	13.04	<0.01	3.91	Rse=1	11.32	85.51	70.03	<0.01	3.08
deet=1	58.06	35.69	29.17	<0.01	3.71	ben=1	10.24	98.55	89.25	<0.01	2.98

Cl/Mod describes the % of the variable in the cluster; Mod/Cl describes the % of cluster with the indicated response to described variable; Glob is the % of the variable in the sample; p.val=p.value; v.test is the critical threshold of significance for a variable, higher values indicate greater significance, negative values indicate negative correlation;

Dichotomized variables: AWv, aware of WNV (Y-yes; N-no); bar, perceived barriers to RPM use (0-none, 1-some); ben, perceived benefits to RPM use (0-none, 1-some); bit, bitten by mosquitoes (0-none, 1-often); deet, uses deet usually or always (0-never, 1-usually or always); protcl, protective clothing (0-never, 1-usually or always); Rph, Public health authority's responsibility to protect from WNV (0-disagree, 1-agree); Rse, self responsibility to protect from WNV (0-disagree, 1-agree); see, perceived exposure (i.e. see mosquitoes often; 0-never, 1-often); sev, perceived severity of WNV (0-none, 1-high).

Other variables: anx, worry about WNV (1 – strongly disagree, 3-neutral, 5- strongly agree); kwnv, WNV knowledge score (0-none,4-highest); mpb, perceived mosquito problem (0-none, l-low, m-moderate, h-high); RO, perceived risk to others of WNV (-1-don't know, 1-minor, 2-moderate, 3-major); RS, perceived risk to self of WNV (1 – strongly disagree, 3-neutral, 5- strongly agree); q0qc, administrative region (QC=Quebec city capitol region, MTL=Montreal, LAU=Laurentians).

Discussion

This study aimed to examine knowledge, perceptions and behaviours of residents of southern Quebec with respect to mosquitoes and West Nile virus (WNV). Our results suggest that current awareness levels of WNV (90%) and adoption of RPMs are generally good and have remained relatively stable since the last regional survey conducted in the province (Fall 2004 reported in (20)). Over three quarters of respondents knew that WNV is transmitted by mosquitoes and report practicing more than one RPM (91% use screens usually or always). This is similar to previous reported results from provincial and national surveys (24,26,27,33).

Examining the reported use of specific RPMs suggests improved adoption for protective clothing and repellent use. Habitual (usually or always) repellent use was up to 85% compared to 47% found in 2004 (20); however, reported DEET use has decreased with only 64% found in our study. Reported protective clothing use increased to 74% compared with 57% found previously (20) (50% among Montreal area respondents in the 2013 evaluation (34)). While source reduction of standing water around one's property was not explicitly measured in the province in 2004, the 64% reported adoption of this behaviour is similar to results found elsewhere in Canada (14,26) and the US (13,15,18,22).

These RPM adoption numbers are encouraging from a Public Health perspective as they suggest that residents are for the most part familiar with RPMs and practice them regularly. This is good news with respect to reducing the risk to WNV and other mosquito-transmitted diseases. It is however difficult to separate RPM adoption motivated by the presence of nuisance mosquitoes versus adoption as a result of WNV sensitization efforts.

Delving further into our sample of respondents via exploratory MCA analysis suggests that respondents' reported RPM adoption is driven both by

perceived exposure to mosquitoes and concern about WNV (among other factors) and that distinct subsets of the population may exist with different motivations for RPM use. Groups with high concern regarding WNV and exposure to mosquitoes adopt more RPMs than those with low concern and little exposure. However, those with high perceived exposure to mosquitoes and lower concern about WNV still adopted RPMs and those with little to no perceived exposure to mosquitoes adopt few if any RPMs. Knowledge of WNV alone was not found to be sufficient to motivate RPM adoption in the absence of high perceived exposure.

Perceived exposure aside, a potential alternative explanation for the reported high RPM adoption levels may be related to the concurrent presence and ongoing emergence of Lyme disease in Southern Quebec (45). Recent public health messaging around Lyme disease may be contributing to heightened awareness and adoption of RPMs in general.

While reported RPM adoption is good, perceived severity and specific knowledge of WNV appear to have decreased in the province (high perceived severity was 22% in our study vs 60% in (20) and 60% had correct knowledge of WNV transmission vs 90% in (20)). This observed decrease may be related to increased familiarity with WNV and generally low reported incidence of the disease in the population over recent years (46,47). Public health should continue to monitor this trend and RPM adoption levels to see how these may continue to change over time. WNV cases are primarily asymptomatic (7) and thus under reporting is likely to occur. Furthermore, other mosquito-borne (e.g.: EEE and snowshoe hare virus) (48,49) and vector-borne disease (e.g. Lyme disease (45)) risks exist in the province therefore good RPM adoption while outdoors is warranted in the province since a potential for exposure to disease carrying mosquitoes and other arthropod vectors such as ticks exists in the province.

Regional variation

A secondary objective of this study was to examine whether differences in knowledge, perceptions or behaviours might exist between the regions immediately surrounding the greater region of Montreal (Risk Region 1) and other regions of the province (Risk Region 2) to offer potential insight into observed differences in cases and deaths of WNV reported over the last five years in these regions. Some differences were observed with respect to WNV awareness (previously heard of WNV prior to survey), perceived self-efficacy to avoid mosquito disease, perceived WNV severity, perceived exposure (see or bitten by mosquitoes) and ecological proximity (garden access or visits to wooded areas) reported by respondents which was generally higher in Risk Region 2. The responses collected from respondents in these two regions suggest different exposure patterns to mosquitoes between the regions. Risk Region 2 is generally more rural, has a lower urban density and may be more hospitable to certain species of mosquitoes. More participants from Risk Region 2 reported seeing or being bitten by mosquitoes often and having garden access or visits to wooded areas. While no significant reported behavioural differences were found between the regions, the reported difference in perceived exposure to mosquitoes may be contributing to different levels of familiarity with mosquitoes, risk perception concerning their presence and actual RPM adoption (which may differ from reported adoption) (46,47).

With regards to socio-economic differences between the regions, gender and income distributions were found to be similar between regions; however, some differences were found with regards to education levels, age and mother tongue. Risk Region 1 had a much higher concentration of individuals whose mother tongue was not French, likely due in part to a higher attraction of immigrants to census metropolitan areas (CMAs) such as Montreal (48). According to 2011 Canadian census statistics, Montreal had 12.5% of all

immigrants arriving to Canada (50). Furthermore, the Montreal region has a greater historical proportion of English speaking communities. WNV specific knowledge and behaviour were not found to be significantly different between the regions; however, awareness of WNV and awareness that QC mosquitoes could transmit disease were significantly lower in Risk Region 1. A Canadian expert Panel on Health literacy report from 2008 identified having a mother tongue other than English or French as a potential barrier to having good health literacy (51). Moreoever, while health campaigns are made in French and English, it may be the case that immigrant populations as well as non-French and non-English speaking residents have not fully absorbed and adopted the public health messages on WNV. This is consistent with 2004 findings for the province reporting WNV awareness to be lower among non-francophones (33). Although communication campaigns on WNV were conducted in 2015 in the Montreal region, only 37% in Risk Region 1 reported hearing about WNV in our study. RPM adoption was similar between the two risk regions though repellent users were more likely to be from Risk Region 2.

Limitations

A few limitations are inherent in our study. First, the response rate of participants recruited via the web panel was relatively low (14%) albeit higher than a 2014 study that used the same marketing firm (8.3% reported in (52)). While panel members are rewarded for survey participation, they can receive daily invitations to surveys and are encouraged to only answer those surveys which interest them. The low response rate may be indicative of low popularity of the subject matter. As a result, if only those individuals who were interested in mosquitoes and mosquito-borne disease chose to participate in our survey, reporter and desirability bias may be high. Second, with respect to the profile of respondents, while comparison of our sample population with statistics for the province were similar they also suggest that the lowest income groups were

underrepresented in our sample. These and other non-responders may have had different response profiles compared with our sample population. Web-based surveys necessitate computer/smartphone and internet access, and while cost may not be the main reason why a household might not have internet, it may offer a partial explanation for the underrepresentation of the lowest income group in our sample. A 2016 survey found that while access varied by regions, overall 90% of Quebec households had access to internet and none of the least connected regions were included in our survey sample (53). In some of our analyses, while not significant, there did appear to be a potential income gradient correlated with education suggesting that the lowest income group may be at increased risk if not adopting good RPM practices in risk areas. Income gradients have been found in other studies (though not always in the same direction) and should continue to be considered in future investigations. Furthermore, survey respondents were selected from regions that have had WNV activity in the province and thus their results may not be generalizable to other regions of the province. Third, as is the nature of surveys, respondents are subject to response bias, including memory recall bias and desirability bias to provide the answers they think are correct. The survey was administered in late spring, early summer 2016 when mosquito season was likely not yet at its peak in the province, thus respondents would have had to rely on their memories of summer 2015 for their responses. Non-English and non-French speaking residents were also not included in the survey and their response profiles may have differed from our survey respondents. Finally, the results of the MCA analysis performed should not be inferred to the Quebec population level given the nature of these types of analyses in which no assumption is made about the underlying distribution of the population nor is a model hypothesized but rather a decomposition of the data is created to characterize the structure of the data (54). Nevertheless, these results may offer insights into specific population groups to target for future studies.

Public Health implications

Public health messaging pertaining to WNV in Quebec over the last several years may be having a positive effect as awareness of WNV has remained relatively high and adoption of RPMs is also good. However, current RPM adoption appears primarily motivated by perceived exposure to mosquitoes rather than concern about WNV. Clusters found among our respondents support both motivation hypotheses though knowledge of WNV alone does not appear to determine RPM use. Respondents with higher reported number of RPMs adopted were more likely to report having heard about WNV the year before.

WNV prevalence trends and potentially changing distributions of the disease will need to be monitored in order to continue to help cue good RPM adoption. Messaging will be important during peak WNV season and in areas of the province where WNV may be newly spreading, or undergoing sporadic outbreaks. In particular, regions with little WNV experience should be monitored to help target timely PH messaging and promote good RPM adoption. Those that are rarely exposed to mosquitoes where they live may not have good RPM reflexes and may benefit from timely reminders when visiting WNV risk regions. Those who reported rarely seeing mosquitoes and rarely visiting wooded areas were found to be least aware of WNV and did not perceive themselves or other Quebecers to be particularly susceptible to WNV. This group may be at a higher risk when visiting WNV risk regions, though their current risk may be low in the areas where they reside if they have little to no exposure to mosquitoes. Future studies should investigate how to best reach specific subgroups of the population with targeted public health messaging.

Public health communication will need to stay current on the most effective mediums for reaching target populations as our results support changing patterns of sources used for health information which appear to favour internet use though the sampling may have been biased by the use of a web-

based survey. Additionally, it may be important to consider non-French and non-English messaging in certain regions to ensure that target groups are receiving important and timely health information.

Lastly, there appears to be some message misunderstanding by a small number of respondents who have confused information on Lyme disease versus WNV disease (52% responded that Lyme disease was transmissible by mosquitoes). Some re-working of public health messages on Lyme disease and West Nile virus should be considered to help clarify disease specifics. From an RPM adoption point of view, the messaging mix-up is not a strong concern since recommended RPMs are similar and comparably effective for both diseases. Indeed, joint messaging for prevention when outdoors may be a simpler and clearer message to communicate. However, given differences in specific symptoms and treatment, appropriate disease-specific messaging should be revisited especially in higher risk areas.

Abbreviations

HBM – Health belief model
RPM – Recommended preventive measures
RR1, RR2 – Risk Region 1, Risk Region 2
WNV – West Nile virus

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CHAPTER 5

ASSESSING EFFECTIVE INTERVENTIONS TO MANAGE WEST NILE VIRUS USING MULTI-CRITERIA DECISION ANALYSIS WITH CLIMATE CHANGE SCENARIOS[‡‡]

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Abstract

The recent emergence of West Nile virus (WNV) in North America highlights vulnerability to climate sensitive diseases and stresses the importance of preventive efforts to reduce their public health impact. Effective prevention involves reducing environmental risk of exposure and increasing adoption of preventive behaviours, both of which depend on knowledge and acceptance of such measures. When making operational decisions about disease prevention and control, public health must take into account a wide range of operational, environmental, social and economic considerations in addition to intervention effectiveness. The current study aimed to identify, assess and rank possible risk reduction measures taking into account a broad set of criteria and perspectives applicable to the management of WNV in Quebec under climate related transmission scenarios. A participatory approach was used to collect information on categories of concern to relevant stakeholders with respect to WNV prevention and control. Multi-criteria decision analysis was applied to examine stakeholder perspectives and their effect on strategy rankings under climate change scenarios. Twenty-three preventive interventions were retained for evaluation using eighteen criteria identified by stakeholders. Combined evaluations revealed that, at an individual-level, *inspecting window screen integrity, wearing light colored, long clothing, eliminating peridomestic larval sites* and *reducing outdoor activities at peak times* were top interventions under six WNV transmission scenarios. At a regional-level, the use of *larvicides* was a preferred strategy in five out of six scenarios, while use of *adulticides* and *dissemination of sterile male mosquitoes* were found to be among the least favoured interventions in almost all scenarios. Our findings suggest that continued public health efforts aimed at reinforcing individual-level preventive behaviours combined with the application of larvicides to manage the risk of WNV infection are the interventions most acceptable and effective at reaching

current management objectives now and under future theoretical climate change transmission risk.

Keywords: West Nile Virus, Vector-borne diseases, Zoonoses, Climate Change, Global Change, Adaptation, MCDA, Multi-criteria decision analysis

Introduction

West Nile virus (WNV) is a mosquito-borne flavivirus that first emerged in North America in New York City in 1999 [1,2] and in Canada in 2001 [3,4]. Most WNV infections are asymptomatic, but an important proportion can result in febrile illness with general muscle weakness (approximately 25% of infections) and in rare cases, more severe neurologic symptoms or death (less than 1% of infections) [5]. In the United States of America (US) alone, approximately 42,000 combined cases of neuroinvasive and non-neuroinvasive cases of WNV were reported between 1999 and 2015 with more than 1,700 associated deaths [6]. Over 5,200 cases were reported in Canada between 2002 and 2014, representing a much higher incidence rate relative to reports from the US (given Canada's approximately 10 times smaller population) [7].

WNV's emergence in the eastern Canadian province of Quebec in 2002 was linked to climatic conditions that occurred that year [8]. Vector-borne and zoonotic diseases (VBZD), such as WNV, are sensitive to changes in weather and climate [9] and incidence is anticipated to change in response to changes in climate [9–12]. Furthermore, multiple factors including weather are known to affect the transmission and distribution of WNV [13] and climatic projections for Quebec predict rising average temperatures (particularly in winter) and increased average precipitation [14]. As such, early preparedness and planning for current

and future VBZD transmission dynamics is a key management strategy for improving public health adaptation to risks posed by climate change.

To date, WNV transmission dynamics have shown themselves to be largely unpredictable in the short term thereby increasing the need to elaborate management strategies that can cover a large range of epidemiologic scenarios [9]. Human transmission of WNV in North America follows a seasonal pattern and is the result of a complex ecology of interacting species. The virus is maintained in an enzootic transmission cycle between birds and mosquitoes, primarily of the Culex genus, with occasional, dead-end infection in humans and other mammals generally appearing later in the summer season when virus amplification has reached a peak in its avian hosts and mosquito density is at a maximum [5,15–17].

Due to the zoonotic nature and transmission dynamics of WNV, prevention and control opportunities should take place at a number of intervention levels, including: the avian reservoir, the mosquito vector or the human accidental host populations. Known prevention and control strategies range from preventive interventions aimed at individuals, such as the use of mosquito repellents and wearing protective clothing, to vector control interventions, including the application of larvicides or habitat modification measures to reduce mosquito abundance [15–19]. Environmental control interventions aimed at the avian reservoir or the mosquito population have important operational, environmental, and social impacts. These impacts need to be accounted for above and beyond the cost of the interventions alone to ensure feasibility, acceptability and sustainability of the interventions. Although effective WNV vaccines exist for horses; a commercial human WNV vaccine does not yet exist [20–22]. Research is ongoing and a number of promising candidate vaccines that have successfully undergone Phase I and Phase II clinical trials are in

development; however, poor perceived cost-benefit of mass vaccination is often cited as the reason for lack of a licensed vaccine for humans at this time [20–22].

Prevention and control of West Nile virus in the province of Quebec (Canada) has primarily consisted of source control of mosquito populations via the use of larvicides, integrated surveillance of humans, animals and mosquitoes, as well as sensitization of the public regarding personal protection measures (21). Uncertainties over the fluctuating yearly numbers of human cases and challenges relative to the perceived high cost of vector control activities in the context of fiscal restraint and government deficits provide ground for periodic re-assessment of the most effective risk reduction strategies. Furthermore, understanding and effectively tackling climate sensitive diseases such as WNV calls for a multidisciplinary perspective and multi-sectoral collaboration [23–25]. Doing so will require transparent approaches that can keep sight of the overarching goal (i.e. reducing public health burden of disease) while taking into account multiple categories of concern, informed by a comprehensive review of available evidence and best-practices [24]. A multi-criteria decision analysis (MCDA) informed approach with multiple stakeholders can help structure reflection and aid in decision-making on the basis of multiple, potentially conflicting criteria (designed to measure specific categories of concern) [26] thereby providing a structured mechanism for multidisciplinary and multi-sectoral collaboration on a decision problem. MCDA enables the ranking of multiple interventions based on a list of stakeholder identified and weighted concerns (i.e. decision criteria) and thus allows for an appreciation of the relative strengths and weakness of various interventions under consideration.

In the current study, preventive interventions for the management of WNV were identified, assessed and ranked using a multi-stakeholder informed MCDA to document effective, favoured and acceptable interventions relating to management of the disease in Quebec under varying climate change transmission

scenarios in order to help inform future seasonal operational decision making at the provincial level.

Materials and methods

A participatory methodology was adapted from an existing MCDA model for Lyme disease management [27]. MCDA is a formal method that can be used to combine evidence-based information and stakeholder values to support decision-making (Fig 8) [26]. The MCDA method consists first of a 'problem structuring' phase. This phase describes the decision problem and identifies a list of management interventions and the important criteria that need to be taken into account when evaluating these interventions. Discussion of the proposed criteria and intervention list by participants ensures exhaustiveness and transparency. Interventions are evaluated using peer-reviewed, grey literature and available data pertaining to all of the retained criteria. Criteria are then weighted by importance by all stakeholders using a standardized form, under different epidemiological transmission scenarios. This allows stakeholders to modify the relative importance of decision criteria (e.g.: incidence reduction vs. cost), depending on the situation they are faced with (ex: low-risk scenario vs. high-risk scenario) and their perspective of the decision problem. The 'problem structuring' phase is richest when performed with a varied group of stakeholders, allowing for the integration of multiple concerns (i.e. criteria), and creating the opportunity to build a common understanding of the decision problem. The second stage of the MCDA process is the 'decision analysis' phase, where the MCDA analysis tool is used to aggregate the information collected in the first phase (i.e. intervention evaluations and criteria weights) in order to produce a relative ranking of assessed interventions.

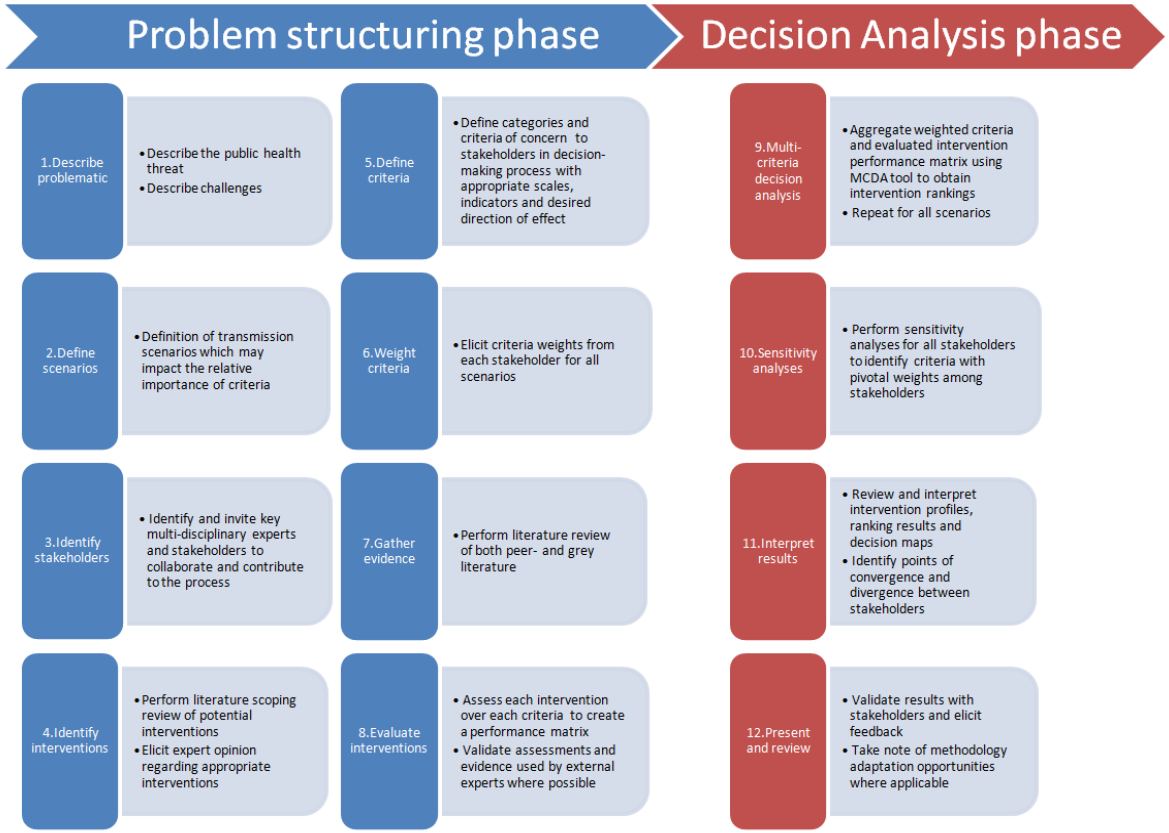

Figure 8. Schematic representation of the MCDA approach.
Adapted from [27].

Transmission scenarios

Interventions for the prevention and control of human WNV in the province were evaluated under current and future possible transmission scenarios of WNV in order to support governmental decision making. We constructed six scenarios to reflect potential increases in transmission under climate change and natural yearly fluctuations of the disease. The scenarios themselves are hypothetical and do not reflect historical reality, nor do they reflect a scientific consensus on expected future conditions, rather these scenarios depict fictional, yet climatically plausible WNV transmission scenarios for the province of Quebec [28]. For each scenario, a combination of WNV transmission risk intensity (low, medium and high) and interventions having taken place during the current season were described (Table XVIII).

Table XVIII. Climate change transmission scenarios assessed under the MCDA model for West Nile virus interventions in Quebec

Scenario	Scenario description	Management context and interventions advocated for WNV season underway
1 **low-risk** - *without interventions* - « Current », end of season, low intensity – Decision for next year	At the end of September, 26 cases declared. All declared cases are symptomatic and distributed among two of the nine sociosanitary regions of Quebec within which human transmission of WNV were previously documented. Clinical presentation of cases was consistent with literature reported symptoms. Passive surveillance of equines (MAPAQ) and of wildlife birds (CQSAS) is coherent with human surveillance data (with respect to the number and geographical distribution of cases). Entomological surveillance data suggests a high density of mosquitoes for the current season, but little WNV found in circulation at present.	Since few WNV cases declared in past two years (< 10) and few resources available to coordinate interventions at beginning of the season, primary intervention strategy for the current season has primarily consisted of providing WNV related information on the ministry website (MSSS)
2 **low-risk -** *with interventions* - « Current », end of season, low intensity - Decision for next year	At the end of September, 26 cases declared. All declared cases are symptomatic and distributed among two of the nine sociosanitary regions of Quebec within which human transmission of WNV were previously documented. Clinical presentation of cases was consistent with literature reported symptoms. Passive surveillance of equines (MAPAQ) and of wildlife birds (CQSAS) is coherent with human surveillance data (with respect to the number and geographical distribution of cases). Entomological surveillance data suggests a high density of mosquitoes for the current season, but little WNV found in circulation at present.	Previous year, 23 cases declared. WNV a concern for Quebec population. Series of interventions carried out at beginning of transmission season. Primary interventions at provincial level: providing WNV related information on ministry website (MSSS). Application of larvicides within risk zones. Calls for vigilance to network medical practitioners. Large scale communication campaign
3 medium**-risk -** *without* interventions - « Outbreak», mid-season, high intensity – Rapid decision for current season	At end of July, 40 symptomatic cases declared to ministry. (Historically, majority of cases occur mid-Aug.-Sep.). 10 cases from regions where no human or animal cases have ever been recorded, suggesting geographical expansion of virus into new zones. Meteorological forecasts predict hot and dry summer. Passive surveillance of equines (MAPAQ) and wildlife (CQSAS) coherent with human surveillance data and suggest acute viral activity compared with data collected over past two years. Among WNV infected horses, 3 declared from regions where no human cases were previously declared and where WNV virus circulation never previously recorded. Entomological surveillance data suggest an increase in mosquito activity and circulation of virus (high density of Culex pipiens and high level of infection). Past two weeks, vector index (number of infected mosquitoes) on rise.	Since few WNV cases declared in past two years (< 10) and few resources available to coordinate interventions at beginning of the season, primary intervention strategy for the current season: providing WNV related information on the ministry website (MSSS)
4 medium**-risk -** *with interventions* - « Outbreak», mid-season, high intensity – Rapid	At end of July, 40 symptomatic cases declared to ministry. (Historically, majority of cases occur mid-Aug.-Sep.). 10 cases from regions where no human or animal cases have ever been recorded, suggesting geographical expansion of virus into new zones. Meteorological forecasts predict hot and dry summer. Passive surveillance of equines (MAPAQ) and wildlife (CQSAS) coherent with human surveillance data and suggest acute viral activity compared with data collected over past two years. Among WNV infected horses, 3 declared from regions where no human cases were	Previous year, 23 cases declared. WNV a concern for Quebec population. Series of interventions carried out at beginning of transmission season. Primary interventions at provincial level: providing WNV related information on ministry website (MSSS). Application of larvicides within risk zones. Calls for

decision for current season	previously declared and where WNV virus circulation never previously recorded. Entomological surveillance data suggest an increase in mosquito activity and circulation of virus (high density of Culex pipiens and high level of infection). Past two weeks, vector index (number of infected mosquitoes) on rise.	vigilance to network medical practitioners. Large scale communication campaign
5 **high-risk** - *without interventions* - « Epidemic», end of season, high intensity - Decision for next year	End of September, 800 symptomatic cases declared. 40 cases from regions where no animal or human cases previously recorded, suggesting a geographical expansion of the virus into new zones. Passive surveillance of equines (MAPAQ) and wildlife (CQSAS) are coherent with human surveillance data and appear to suggest acute viral activity compared with data collected over past two years. Among WNV infected horses, 12 declared from regions where no human cases were previously declared and where virus circulation never previously recorded. Moreover, 72 birds submitted to CQSAS (passive surveillance) tested positive for WNV. Entomological surveillance suggests an increase in mosquito activity and circulation of virus (high density of Culex pipiens and high level of infection). Past four weeks, vector index (number of infected mosquitoes) increasing significantly.	Since few WNV cases declared in last two years (< 10) and few resources available to coordinate interventions at beginning of the season, primary intervention strategy for the current season: providing WNV related information on the ministry website (MSSS)
6 **high-risk** - *with interventions* - « Epidemic», end of season, high intensity - Decision for next year	End of September, 800 symptomatic cases declared. 40 cases from regions where no animal or human cases previously recorded, suggesting a geographical expansion of the virus into new zones. Passive surveillance of equines (MAPAQ) and wildlife (CQSAS) are coherent with human surveillance data and appear to suggest acute viral activity compared with data collected over past two years. Among WNV infected horses, 12 declared from regions where no human cases were previously declared and where virus circulation never previously recorded. Moreover, 72 birds submitted to CQSAS (passive surveillance) tested positive for WNV. Entomological surveillance suggests an increase in mosquito activity and circulation of virus (high density of Culex pipiens and high level of infection). Past four weeks, vector index (number of infected mosquitoes) increasing significantly.	Previous year, 23 cases declared. WNV a concern for Quebec population. Series of interventions carried out at beginning of transmission season. Primary interventions at provincial level: providing WNV related information on ministry website (MSSS). Application of larvicides within risk zones. Calls for vigilance to network medical practitioners. Large scale communication campaign

Identification of stakeholders

Stakeholders (n=15) already involved in WNV management from various levels of government, academia as well as from an existing expert committee on WNV in Quebec were invited to participate in the MCDA process in April 2014. Invited stakeholders included individuals from the National institute of public health, Ministry of health and social services, the Public Health Agency of Canada, Ministry of sustainable development, environment and the fight against climate change, the academic sector, the Quebec center for wildlife health, companies involved in mosquito control operations, Ouranos Consortium for research in climatology and adaptation to climate change and Quebec regional public health authorities. The protocol for this project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (Comité d'éthique de la recherche en santé, CERES) (certificate number 14-025-CERES-D). All participants gave informed consent for inclusion prior to participation in the study.

Identification of potential interventions

A literature scoping review was conducted to construct a preliminary list of interventions for discussion with stakeholders [5,17,19,29–31]. Interventions including active and passive surveillance, large scale and targeted communication campaigns and various prevention and control interventions were included in this preliminary list. Interventions under development and implementable under both a short and long-term perspective were included in order to provide a range of options to cover all transmission scenarios. A baseline, status quo intervention encompassing passive surveillance of human cases and representative of what is currently done to manage WNV in the province was also included (please note that interventions will hereafter be shown in italics in the text while criteria will be shown in "quotes" to ease readability). The proposed interventions were then

discussed and validated with participating stakeholders during a focus group discussion. Individual feedback was solicited from all stakeholders following the discussion by means of a Delphi survey during which stakeholders had the opportunity to suggest additional interventions previously missed [32]. Consensus was not explicitly sought during this process; rather stakeholders agreed that an intervention would be retained in the model so long as at least one stakeholder deemed it pertinent to include.

Identification of decision criteria

Drawing from previous work [27,33], a preliminary list of 15 evaluation criteria, distributed over five categories ("Public Health" criteria, "Social Impact" criteria, "Economic" criteria, "Strategic and Operational", and "Animal and Environmental Health" criteria) was compiled by the research team. Each criterion was defined with a measurement scale (allowing for a quantitative or qualitative assessment of an intervention), including a direction of desired effect. Linear preference functions were used with all criteria and qualitative assessments were transformed into monotone ascending or descending scales depending on the direction of the desired effect [34]. The relevance of criteria and their measurement scales was discussed and validated with stakeholders. Individual feedback was also solicited via a Delphi survey [32]. Once again, consensus was not explicitly sought regarding retained criteria; rather a criterion was retained so long as at least one stakeholder deemed it pertinent. Weights of zero were permitted by stakeholders to indicate absence of importance for a given criterion during the weighting process (described in the following section).

Criteria weighting

Stakeholders were asked to weight the relative importance of criteria under all transmission scenarios. Scenarios were presented to stakeholders as

hypothetical yet climatically plausible transmission scenarios meant to examine the effect of changing criteria trade-offs under different transmission intensities. For the weighting exercise, stakeholders were given a Microsoft Excel spreadsheet tool and asked to distribute 100 points across the list of criteria included in the model. The more points given to a criterion, the more important this criterion for the stakeholder, thus permitting a relative ranking of criteria. The process was repeated for each of the six scenarios by all stakeholders. Differences in assigned weights were tested between groups of stakeholders using Welch's *t*-test (unequal variances *t*-test) in R (version 3.3.0) to test for differences in the mean category weights.

Evaluations of interventions

Assessments were performed for all interventions over every criterion using measurement scales discussed and finalized with stakeholders (see supplemental Table XLIII in Appendix 4). Evaluations were based on existing peer-reviewed evidence, grey literature and available data (see supplementary documents for the results of this evaluation - Table XLIV and supporting references in Appendix 4). A comprehensive literature review was performed for all interventions. When data were not available for an evaluation, expert judgment was used. All information relative to the evaluations was compiled into an assessment matrix then revised and discussed by all evaluators. Assessments were further reviewed and validated by external experts with specific field or research experience.

The population specific criterion ("proportion affected") was assessed as the estimated proportion of the population currently employing these measures for individual-level interventions in population-level analyses. Where data were incomplete, the incidence reduction criterion was assessed as either known to reduce cases or reducing contact between vectors and human hosts. The

entomological risk reduction criterion was assessed with regards to having an effect on reducing the population or density of mosquitoes. Data availability and reliability of assessments was tracked to reflect the degree of certainty over provided assessment distinguishing literature based assessment versus expert opinion or field tested result.

Multi-criteria decision analysis

The evaluations of all interventions were aggregated with criteria weights and analyzed using a multi-criteria analysis tool. The PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) [34] was used to perform multi-criteria analysis with the D-Sight software (version 3.3.2, D-Sight company). Geometrical analysis for interactive aid (GAIA) analysis maps, available with the D-Sight software, were also used to aid in visual interpretation of results [35,36]. Two main sets of analyses were performed, one based on individual-level interventions (n=11) and the second based on regional-level interventions (n=10). A subset of mosquito-targeting control measures (n=8), as well as a subset of the currently available interventions (i.e. interventions ready for deployment within the next year in the province; n=5), were analysed separately. For the purpose of exploratory comparison, an analysis of combined individual-level and regional-level interventions was also performed. Following this, sensitivity analyses were performed on all criteria and for all stakeholders to examine the robustness of rankings and identify potentially weight-sensitive criteria.

Results

Stakeholder consultation and MCDA model construction

Twelve stakeholders (out of 15 invited) consented to participate in the study. Following presentation and discussion of the preliminary lists of interventions and criteria with stakeholders, a final list of 23 interventions (Table XIX) and 18 evaluation criteria were retained (Table XX). The identified interventions included individual protective measures, mosquito source reduction measures, adult mosquito control measures, and interventions aimed at the animal reservoir. Four of the twenty-three interventions were not assessed due to insufficient information in the literature to do so (*use of lethal ovitraps*, *reduction in abundance of the main animal reservoir*, *modification of animal reservoir habitat*, and *increased biodiversity at the peridomestic level*). Although communication and surveillance interventions were explicitly recognized as important elements within a VBZD management programme by stakeholders, these interventions were not included in the current model due to concerns regarding the ability to properly assess the efficacy of these interventions under one comprehensive model. The consensus was to explore these interventions separately in a future exercise.

Table XIX. Potential protection and control interventions for the management of West Nile virus in Quebec

Scale	Category	Code	Interventions	Description
Individual-level				
	Personal protection measures			
		INT-1	Use of mosquito repellent	Ex.: DEET, citronella, p-menthane-3,8-diol applied to skin
		INT-2	Use of domestic insecticides	Ex.: aerosols, torches, spirals, etc.
		INT-3	Use of alternative technologies	Ex.: automatic insecticide dispensers, electric traps, etc.
		INT-4	Wearing light colored, long clothing	Use of robust and tightly woven fabric
		INT-5	Reducing outdoor activities at peak times	Reduce outdoor activities in high risk areas at dusk and dawn
		INT-6	Reinforcing the immune system	Via healthy living and lifestyle
		INT-7	Inspecting window screen integrity	
		INT-8	Human vaccination	
		INT-9	Wearing insecticide treated clothing*	Insecticide treated clothing
	Source reduction			
		INT-10	Eliminating peridomestic larval sites	Stagnant water, rain water barrels, pails, pool covers, drains
Regional-level				
	Vector targeted source reduction measures			
		INT-11	Modification of natural larval sites	Ex.: water banks, swamps, marshes,
		INT-12	Modification of man-made larval sites	Ex.: treated water basins, reservoirs, damns, roadside ditches, catch basins, underground water canals, vacant and commercial lots, snow disposal sites, used tire sites
		INT-13	Use of parasites and pathogenic micro-organisms	Ex.: nematodes, mushrooms
		INT-14	larvicides	Ground application of larvicides at identified mosquito breeding sites
	Vector targeted population control measures			
		INT-15	Use of mosquito predators	Ex.: birds, bats, fish, insects
		INT-16	Dissemination of sterile males#	Use of sterile male mosquitoes or other compatible insects
		INT-17	Use of lethal ovitraps *†	Traps destined for females with lethal liquid
		INT-18	Use of adulticides	Treatment by truck or plane
	Animal reservoir targeted measures			
		INT-19	Vaccination of animal reservoir *#	Vaccination of the main animal reservoir Ex.: vaccination of American blackbirds
		INT-20	Reduction of the main animal reservoir *†#	Ex.: controlled reduction of American blackbirds
		INT-21	Modification of animal reservoir habitat *†#	Ex.: move American blackbird dormitories away from inhabited areas
		INT-22	Increase biodiversity at peridomestic level *†#	Ex.: attract other birds near habitat (to reduce circulating levels of the virus)

Scale	Category	Code	Interventions	Description
	Other measures			
		INT-23	Status quo – Human passive surveillance	Encourage research and knowledge transfer regarding control and prevention methods
		INT-24	Large scale communication campaign †	Ex.: media campaign, social media, etc.
		INT-25	Targeted communication campaign †	Ex.: health professionals (detection of new cases)
		INT-26	Active surveillance †	Ex.: mosquitoes, birds, human cases

* Interventions added following discussion with stakeholders

† Interventions not assessed due to insufficient data or following discussion with stakeholders

Interventions in development, not currently implementable

Note: *Interventions* are listed in *italics* when referenced in the text to distinguish from "criteria" which are listed in "quotes"

Table XX. Criteria for the management of West Nile virus in Quebec

Category	WNV criteria	Description
Public Health Criteria (PHC)		
	PHC1 - Incidence reduction	Reduction in incidence of human cases
	PHC2 - Entomological risk reduction	Reduction of entomological risk
	PHC3 –Physical health impact	Impacts to human physical health
	PHC4 - Mental health impact	Impacts to human mental health
	PHC5 – Social equity*	Impact on social equity
	PHC6 – Reduction of circulating virus	Reduction in level of circulating virus in animal reservoir
	PHC7 – Proportion affected	Proportion of population that benefits from the action
Social Impact Criteria (SIC)		
	SIC1 – Public acceptance	Level of public acceptance
	SIC2 – Impact to credibility	Impact to confidence in and credibility of organisation in charge
Economic Criteria (ECC)		
	ECC1 – Government cost	Cost to the government
	ECC2 – Municipal cost	Cost to municipalities
	ECC3 – Individual cost	Cost to individuals and private sector
Strategic & Operational Criteria (SOC)		
	SOC1 - Delay	Delay before appearance of desired effect
	SOC2 – Complexity	Institutional and operational complexity of the action
	SOC3 – Sustainability *	Sustainability of the action
	SOC4 – Other policy impact*	Impact on other public policies
Animal & Environmental Criteria (AEC)		
	AEC1 – Animal health impact	Impact on animal health
	AEC2 – Environmental impact	

* Criteria added following discussion with stakeholders

Note: Criteria are listed in “quotes” when referenced in the text to distinguish from *interventions* which are listed in *italics*

Criteria weighting

Stakeholder weights for the criteria under all scenarios are included in the supplementary material (see supplementary tables XLIII-XLV in Appendix 4 for the individual weighting results). The criteria deemed most important (most points attributed per criterion by stakeholders), were predominantly criteria related to the "Public Health" category, followed by the "Economic" category or the "Strategic and Operational" criteria category. In nearly all transmission scenarios, "Animal and Environmental Health" criteria ranked lowest, with fewest weights attributed by stakeholders. Within the "Public Health" category, a majority of weights were attributed to the "incidence reduction" criterion, and "physical health impact" criterion. Within the "Social Impact" category, the "credibility impact" criterion received the highest weight in most scenarios. Within the "Economic" criteria category, the "government cost" criterion received the highest weight. Within the "Strategic and Operational" criteria category, the "delay" criterion was given highest weight for medium and high scenarios. Finally, in the "Animal and Environmental Health" criteria category, the "environmental impact" criterion was given the highest weight for all scenarios.

Global results

A strong level of congruence was generally observed among weights expressed by stakeholders across all scenarios. The high-risk transmission scenario analysis of regional-level interventions illustrates this (Fig 9). In figure 9, two semi-coalitions of stakeholders can be observed consisting in one case of stakeholders 4,5,7,9 and 10 and in the second case of stakeholders 1,2,3,5,8,11 and 12. Stakeholder positions are generally all pointing in the same direction as the decision axis indicating that no stakeholders are in direct opposition to the group consensus; however slight differences between these two groups of stakeholder weights can be observed. A statistical comparison of weights

(Welch's t-test, unequal variances) revealed that these two groups of stakeholders had significant differences in weights for the Social impact category as well as the Animal and Environmental Health criteria category. From an organizational standpoint, stakeholders in the 2nd coalition consist of a mix of organizations including public health, wildlife and environmental management. The 1st coalition consists of a mix of wildlife and public health related organizations. The bigger difference between these two groups may be their spatial planning mandates with stakeholders in coalition 2 having more involvement in daily field operations and stakeholders from coalition 1 being more involved at a regional planning scale, though not strictly so. Both points of view are important to take into account and despite their differences in weighting; there is a consensus with regards to recommended interventions. Stakeholder positions were seen to converge under scenarios of increasing severity. Sensitivity analyses were performed to examine the robustness of weights given by stakeholders to criteria in the models and their effect on the overall rankings. The criteria most sensitive to stakeholder weights primarily consisted of criteria from the "Public Health" category, as well as the "credibility impact" criterion, "individual cost" criterion and "government cost" criterion.

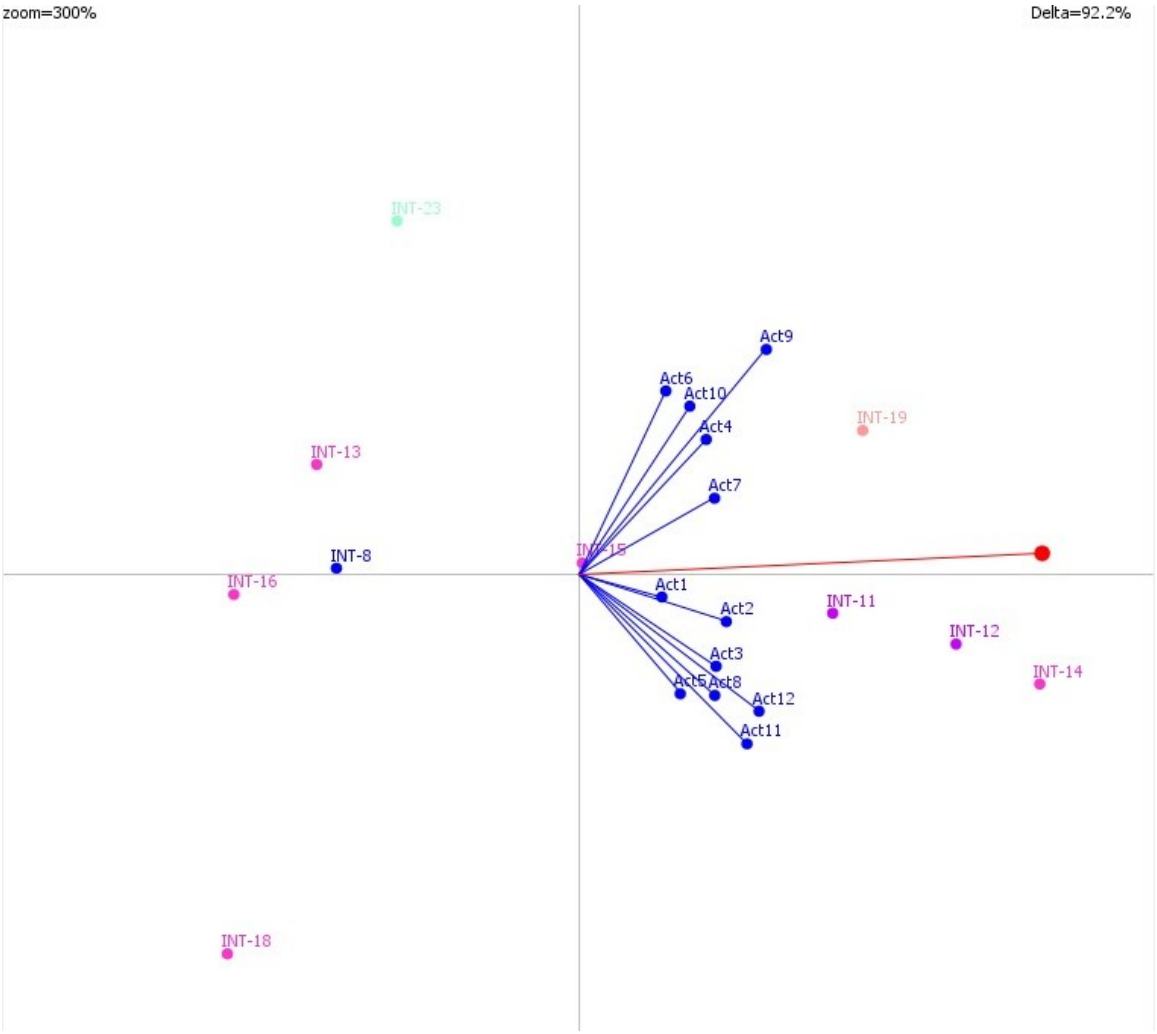

Figure 9. GAIA decision map for regional-level model under scenario 6 (high-risk transmission with interventions).

Vector points Act1 through Act12 represent the 12 stakeholders in the model. Points INT-8-23 represent the various Interventions under consideration in this analysis (see Table XIX). The red vector indicates the group decision axis with preferred direction indicated by the red dot. Proximity of intervention points along the decision axis represents group ranking preference for these interventions. The relatively proximity of all stakeholder points in the same general direction as the decision axis indicates that all stakeholders are generally in agreement with the group decision axis, and no stakeholder is diametrically opposed to this decision. The close proximity of all stakeholders to one another furthermore indicates fairly strong consensus between stakeholders. There are two slightly divergent coalitions of stakeholders (1st group consists of stakeholders above the decision axis and the 2nd group consists of those below) indicating that these two groups have slightly different perspectives with regards to their criteria weighting, but these differences in perspective are not in conflict with the group decision axis. (Zoom=300% and Delta=92.2%, indicates that 92.2% of the information is conserved in the two-dimensional representation of this decision map).

Ranking of individual-level interventions

The top four ranked personal protection interventions, inspecting window screen integrity, wearing lightly colored clothing, and eliminating peridomestic mosquito larval sites, reducing outdoor activities at peak times, were identical across all scenarios (Table XXI). These rankings are based on evidence-based assessment scores combined with stakeholder assigned weights. Fig 10 shows how Inspecting window screen integrity scores high on a majority of criteria with the exception of "entomological risk reduction", "reduction of circulating virus" and "social equality" where it received lower scores. The second and third ranked interventions, wearing light colored clothing and eliminating peridomestic larval sites, also scored highly on a majority of criteria (Fig 10).

The least favoured interventions among this subset varied slightly from one transmission scenario to another, but generally included: use of alternative technologies, human vaccination and status quo. Examination of the profiles for the bottom ranked interventions, status quo and human vaccination, (Fig 9) shows how these interventions score poorly on most criteria including many "Public Health" criteria, a category consistently weighted highly by all stakeholders. Human vaccination in particular scores poorly over many criteria, notably "entomological risk reduction", "physical health impact", "social equity" (if not covered by universal health care, then some costs must be incurred by the general public for vaccination), "public acceptance", "credibility impact", "government cost", "individual cost", "delay", and "complexity" (highly complex since licensed human vaccine not yet available).

Table XXI. Ranking of the individual-level protection interventions

Scenarios	Low risk				Medium risk				High risk			
	1		2		3		4		5		6	
Intervention	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow
INT-01 Use of mosquito repellent	5	-0	5	-0	6	-0	6	-0	6	-0.02	6	-0
INT-02 Use of domestic insecticides	8	-0.1	8	-0.1	7	-0.1	7	-0.1	8	-0.11	8	-0.1
INT-03 Use of alternative technologies	9	-0.1	9	-0.1	8	-0.1	9	-0.1	9	-0.11	9	-0.1
INT-04 Wearing light colored, long clothing	2	0.19	2	0.17	2	0.22	2	0.22	2	0.23	2	0.22
INT-05 Reduction of activities at peak times	4	0.09	4	0.07	4	0.09	4	0.08	4	0.09	4	0.08
INT-06 Reinforcing the immune system	6	-0	7	-0.1	9	-0.1	8	-0.1	7	-0.05	7	-0.1
INT-07 Inspecting window screen integrity	1	0.22	1	0.23	1	0.25	1	0.25	1	0.27	1	0.25
INT-08 Human vaccination	11	-0.2	11	-0.2	11	-0.2	11	-0.2	10	-0.19	10	-0.2
INT-09 Wearing insecticide treated clothing	7	-0	6	-0	5	0.01	5	0	5	0.03	5	0.01
INT-10 Eliminating peridomestic larval sites	3	0.12	3	0.11	3	0.11	3	0.1	3	0.10	3	0.11
INT-23 Status quo	10	-0.2	10	-0.1	10	-0.2	10	-0.2	11	-0.23	11	-0.2

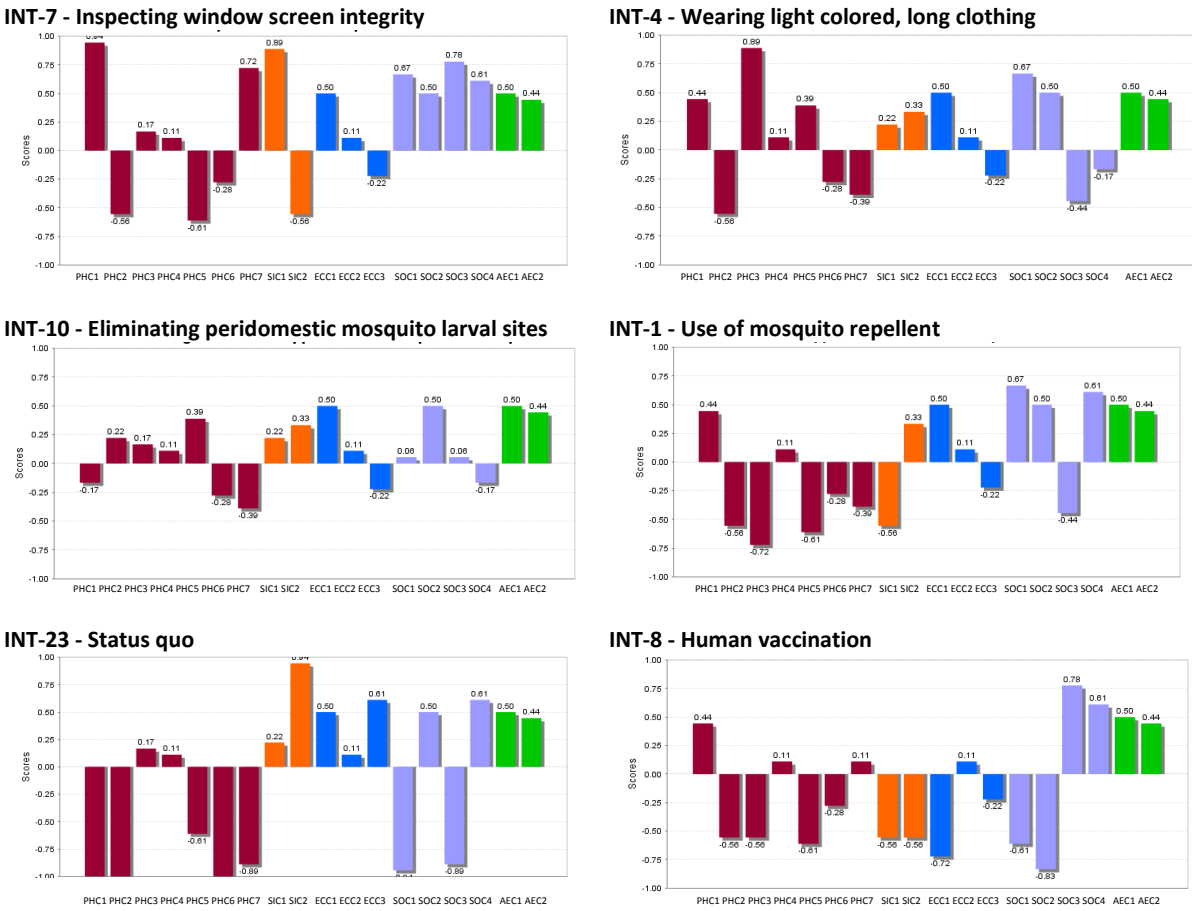

Figure 10. Intervention profiles for six individual-level protection interventions.

Each bar represents one of the criteria included in the model. Values along the vertical axis indicate the scores received for the intervention on a particular criterion. Values above zero indicate good performance of the intervention for that criterion based on evaluation scores and conversely, values below zero indicate "poor" relative performance. Criteria bar color codes: red: Public Health criteria; orange: Social Impact criteria; blue: Economic criteria; purple: Strategic and Operational criteria; green: Animal and Environmental Health criteria.(Please refer to supplementary material for all other intervention profiles).

Ranking of regional-level interventions

In the model containing regional-level management interventions (Table XXII), the top three identified interventions were consistently: *larvicides*, v*accination of animal reservoir* and *modification of man-made larval sites* with small variations in the order of these interventions depending on the scenarios. Examination of regional-level intervention profiles showed *larvicides*, *vaccination of animal reservoir* and *modification of man-made larval sites,* to be top scorers over most of the criteria, although *Larvicides* scored less well on the "government cost", "complexity", "other policy impact", "animal health impact" and "environmental impact" criteria (see supplemental figures in Appendix 4). The *vaccination of animal reservoir* intervention was found to score less well on the "incidence reduction" criterion compared to *larvicides*, but scored relatively well on other criteria "reduction of circulating virus" criterion in particular. The *modification of man-made larval sites* intervention scored less well on "Economic" criteria, "Strategic and Operational" criteria and the "Animal and Environmental Health" criteria.

The ordering of the bottom three interventions included: *use of adulticides*, *dissemination of sterile males*, and *human vaccination* in the low and medium-risk scenarios. For the high-risk scenarios, the bottom ranked interventions changed to include *use of parasites and pathogenic microorganisms* instead of *human vaccination*.

Table XXII. Ranking of the regional-level management interventions

Scenarios	Low risk				Medium risk				High risk			
	1		2		3		4		5		6	
Intervention	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow
INT-08 Human vaccination	10	-0.18	8	-0.13	8	-0.17	9	-0.21	7	-0.13	7	-0.15
INT-11 Modification of natural larval sites	5	0.01	6	-0.01	4	0.12	4	0.17	4	0.13	4	0.13
INT-12 Modification of man-made larval sites	3	0.10	3	0.08	3	0.18	3	0.18	2	0.22	2	0.21
INT-13 Use of parasites and pathogenic micro-organisms	7	-0.07	7	-0.07	7	-0.13	7	-0.13	8	-0.16	8	-0.15
INT-14 larvicides	1	0.21	2	0.19	1	0.25	1	0.28	1	0.29	1	0.27
INT-15 Use of mosquito predators	4	0.09	4	0.05	5	0	5	0.02	5	0.02	5	0.01
INT-16 Dissemination of sterile males	8	-0.15	9	-0.16	9	-0.19	10	-0.21	10	-0.21	9	-0.21
INT-17 Use of adulticides	9	-0.17	10	-0.22	10	-0.21	8	-0.19	9	-0.19	10	-0.21
INT-18 Vaccination of animal reservoir	2	0.20	1	0.24	2	0.22	2	0.19	3	0.15	3	0.19
INT-23 Status quo – Human passive surveillance	6	-0.05	5	0.02	6	-0.07	6	-0.10	6	-0.12	6	-0.1

Ranking of mosquito-targeting and currently available interventions

Among the mosquito-targeting interventions (Table XXIII), the top two ranked were *larvicides* and *modification of man-made larval sites*. This was followed by *use of mosquito predators* in the first two scenarios and *modification of natural larval sites* across remaining scenarios. The bottom three ranked interventions included, in order, the *use of parasites and pathogenic microorganisms*, the *dissemination of sterile males* and the *use of adulticides* for the low- and medium- risk scenarios with the ordering of the last two interventions reversed for the two high-risk scenarios.

In the analysis of currently available to deploy regional-level management interventions (Table XXIV), the ranking did not change for any of the six scenarios and included *larvicides*, *modification of man-made larval sites*, *status quo*, *use of parasites and pathogenic microorganisms* and *use of adulticides* in the listed order.

Table XXIII. Ranking of the mosquito-targeted control measures

Scenarios	Low risk				Medium risk				High risk			
	1		2		3		4		5		6	
Intervention	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow
INT-11 Modification of natural larval sites	4	0.01	5	0.00	3	0.12	3	0.17	3	0.12	3	0.13
INT-12 Modification of man-made larval sites	2	0.12	2	0.10	2	0.20	2	0.18	2	0.23	2	0.23
INT-13 Use of parasites and pathogenic micro-organisms	6	-0.08	6	-0.05	6	-0.13	6	-0.14	6	-0.16	6	-0.15
INT-14 Larvicides	1	0.23	1	0.21	1	0.27	1	0.29	1	0.30	1	0.29
INT-15 Use of mosquito predators	3	0.09	3	0.06	4	0.00	4	0.01	4	0.02	4	0.01
INT-16 Dissemination of sterile males	7	-0.16	7	-0.15	7	-0.19	8	-0.22	8	-0.22	8	-0.21
INT-17 Use of adulticides	8	-0.17	8	-0.21	8	-0.20	7	-0.18	7	-0.18	7	-0.20
INT-23 Status quo – Human passive surveillance	5	-0.04	4	0.04	5	-0.06	5	-0.11	5	-0.11	5	-0.09

Table XXIV. Ranking of the currently available management interventions

Scenarios	Low risk				Medium risk				High risk			
	1		2		3		4		5		6	
Intervention	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow
INT-12 Modification of man-made larval sites	2	0.07	2	0.05	2	0.14	2	0.12	2	0.17	2	0.17
INT-13 Use of parasites and pathogenic micro-organisms	4	-0.06	4	-0.05	4	-0.11	4	-0.11	4	-0.14	4	-0.13
INT-14 Larvicides	1	0.23	1	0.21	1	0.27	1	0.31	1	0.29	1	0.29
INT- Use of adulticides	5	-0.21	5	-0.26	5	-0.25	5	-0.22	5	-0.24	5	-0.25
INT-23 Status quo – Human passive surveillance	3	-0.03	3	0.04	3	-0.05	3	-0.09	3	-0.09	3	-0.07

Table XXV. Ranking of the individual-level protection and regional-level management interventions combined

Scenarios	Low risk				Medium risk				High risk			
	1		2		3		4		5		6	
Intervention	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow	Rank	Net Flow
INT-01 Use of mosquito repellent	9	0.00	7	0.06	9	0.05	10	0.02	10	0.02	10	0.02
INT-02 Use of domestic insecticides	11	-0.04	9	0.02	11	0.01	11	-0.02	12	-0.06	11	-0.04
INT-03 Use of alternative technologies	14	-0.11	12	-0.04	12	-0.05	12	-0.07	14	-0.12	14	-0.09
INT-04 Wearing light colored, long clothing	2	0.19	2	0.22	2	0.27	2	0.25	2	0.27	2	0.25
INT-05 Reduction of activities at peak times	5	0.11	4	0.13	4	0.14	5	0.12	4	0.13	5	0.11
INT-06 Reinforcing the immune system	13	-0.06	10	-0.02	13	-0.07	14	-0.08	11	-0.06	12	-0.06
INT-07 Inspecting window screen integrity	1	0.32	1	0.34	1	0.34	1	0.33	1	0.35	1	0.33
INT-08 Human vaccination	17	-0.15	16	-0.15	16	-0.19	17	-0.21	15	-0.14	15	-0.16
INT-09 Wearing insecticide treated clothing	10	-0.02	8	0.03	8	0.05	9	0.07	8	0.05	9	0.03
INT-10 Eliminating peridomestic larval sites	6	0.11	3	0.14	5	0.14	4	0.12	6	0.11	4	0.12
INT-20 Modification of natural larval sites	12	-0.06	15	-0.10	10	0.02	8	0.07	9	0.05	8	0.05
INT-21 Modification of man-made larval sites	7	0.01	11	-0.04	7	0.05	7	0.07	5	0.12	6	0.11
INT-22 Use of parasites and pathogenic micro-organisms	15	-0.12	17	-0.16	17	-0.21	16	-0.19	17	-0.22	17	-0.21
INT-23 Larvicides	3	0.16	6	0.10	3	0.14	3	0.18	3	0.20	3	0.18
INT-24 Use of mosquito predators	8	0.01	13	-0.07	14	-0.11	13	-0.08	13	-0.07	13	-0.07
INT-25 Dissemination of sterile males	18	-0.16	18	-0.22	18	-0.25	18	-0.24	19	-0.26	18	-0.25
INT-27 Use of adulticides	19	-0.19	19	-0.26	19	-0.28	19	-0.25	18	-0.24	19	-0.25
INT-28 Vaccination of animal reservoir	4	0.13	5	0.11	6	0.09	6	0.08	7	0.06	7	0.09
INT-32 Status quo - human passive surveillance	16	-0.12	14	-0.08	15	-0.15	15	-0.17	16	-0.19	16	-0.17

Ranking of combined individual- and regional-level interventions

In the combined model of individual- and regional-level interventions (Table XXV), *inspecting window screens* and *wearing lightly colored clothing* were always ranked 1st and 2nd. This was most often followed by *larvicides* in all but the low-risk scenario 2 where it was replaced by *eliminating peridomestic larval sites*. The bottom three ranked interventions most often included *use of parasites and pathogenic microorganisms*, *dissemination of sterile males*, and *adulticides*.

Discussion

This study has demonstrated adaptation planning for management of WNV under climate change transmission scenarios using multi-criteria decision analysis (MCDA). To the best of our knowledge, this is the first study to use MCDA for climate change management planning of WNV. Aenishaenslin and colleagues (2013) had previously demonstrated the possibility of MCDA use for management of Lyme disease emergence in Canada and had suggested that general criteria categories exist that are suitable for VBZD management at large [27]. The categories retained in our study are consistent with previous multi-stakeholders concerted decisions that have taken place in public health over the past 20 years [33,37,38]. Our study further supports the application of MCDA for VBZD and reinforces the notion of common categories of concern to consider in VBZD management. Additionally, our study has shown how many of these concerns remain relevant under various scenarios of transmission intensity with climate change.

The degree of concern (weights) attributed to different criteria by stakeholders was shown to vary with transmission intensity of scenarios. This was expected as we anticipated that an increasing number of reported cases in the scenarios would lead to increased concern for public health and social impact

related considerations thereby triggering a trade-off among remaining criteria. A similar result was found in the Lyme disease study [27]. A priori hypotheses around economic cost trade-offs were that as WNV incidence increased, costs would become less of a concern with regards to investment in interventions. Indeed, this pattern is observed but is more apparent when scenarios 1,3,5 (scenarios without interventions performed during the current season) are compared together versus scenarios 2,4 and 6 (scenarios where interventions have been carried out during the current season). Despite the decreasing importance of cost under increased transmission intensity, important differences in intervention rankings were not observed. The ranking of interventions was found to vary under different scenarios and among the different models. This was also expected since changes in weights affect rankings. Intervention profiles can be examined to further understand the relative rankings of interventions independently of stakeholder assigned weights (see supplementary material for comprehensive coverage of profiles). Model rankings and interpretation are discussed in more detail in the following sections.

Individual-level protection model

The relative rankings of individual-level interventions were generally not found to vary considerably across the scenarios (low to higher risk transmission). This stability suggests specific protective behaviors that remain effective and acceptable and should continue to be promoted in communication campaigns in order to reinforce adaptive capacity to climate change.

The individual-level model results observed where inspection of window screens, wearing light colored clothing, eliminating peridomestic larval sites and reducing outdoor activities at peak times were highly ranked and use of alternate technologies, human vaccination and status quo were lower ranked are consistent with primary prevention messages already included in Quebec WNV

communication campaigns as well as other Canadian and the US ones [39–41]. These messages are also consistent with personal protection methods prescribed within integrated vector management programs in Europe [18]. The inspection of window screens in particular was the most highly ranked intervention at this level and indeed is already a common and well accepted practice in most homes in the province of Quebec [42]. As such few if any financial costs are expected to be associated with the promotion of this strategy; however, individuals without sufficient economic means may be less likely to replace or purchase window screens. Examination of the relative strengths and weaknesses of interventions via their intervention profiles (see Fig 10 and supplementary Figs 11-13) illustrates how a comprehensive public health strategy can be built that addresses all concerns raised by stakeholders. For example, the second and third ranked interventions, wearing light colored clothing and eliminating peridomestic larval sites, which also ranked highly, are complementary to the inspecting window screen integrity intervention as they score well on criteria where inspecting window screens performed less well (Fig 10).

Regional-level management model

Overall, the rankings of regional-level interventions were found to vary more than individual-level interventions across the climate change transmission intensity scenarios. The positional stability of top ranked interventions here too suggests specific actions to manage WNV effectively that remain acceptable across a range of transmission dynamics. The positional change of other interventions such as vaccination or modification of natural mosquito larval sites, under the higher transmission risk scenarios suggests increased acceptability of potentially more controversial interventions under these conditions. Periodic re-evaluations are warranted as additional information becomes available for these interventions.

Evaluated regional-level interventions were primarily vector targeted with the exception of the vaccination (human and animal) and status quo (human passive surveillance) interventions. Top ranking interventions included larvicides, vaccination of animal reservoir and modification of man-made larval sites having scored highly on most criteria but with important trade-offs on other criteria. For example, Larvicides scored poorly on cost, operational complexity and environmental criteria. Mosquito control programs are costly and complex to operate as they require entomological surveillance programs, well-trained staff and infrastructure [17] and repeated application in order to maintain effectiveness [43,44]. Nevertheless, vector control remains key to effective vector borne disease management [45]. While the vaccination of animal reservoir intervention was highly ranked, the inclusion of a criterion explicitly targeting the level of circulating virus in the animal reservoir may explain the high ranking of this strategy as it is the only measure that directly acts on this aspect of transmission. A few studies have demonstrated success with this measure [46–48] but for the time being, it remains a hypothetical intervention for the province of Quebec. With regards to man-made larval sites, studies have found that proximity to certain types of structures such as combined sewer overflow systems have been significantly associated with high rates of WNV infection in humans and corvids; however, construction and modification of major infrastructure can be very costly [29,49,50]. Additionally, man-made water systems such as those designed to handle sewer overflow may have negative impacts on water quality and animal health by association [51].

Mosquito-targeting and currently available management models

The top ranked mosquito interventions, *larvicides* and modification *of man-made sites,* performed well on most “Public Health” Criteria. However, these interventions had economic, environmental and operational shortcomings that would need to be addressed in any comprehensive public health strategy. In

the model examining only the list of currently available interventions, the rank ordering of interventions did not change for any of the six scenarios and included *larvicides*, *modification of man-made larval sites*, *status quo*, *use of parasites and pathogenic microorganisms* and *use of adulticides* in this order. This stable ranking across scenarios adds to the robustness of these interventions suggesting their capacity to meet current and higher intensity transmission scenario management demands.

Combined model

In the combined model, four out of the top seven interventions included individual measures. This suggests that based on available evidence, current epidemiological levels of WNV, and values held by experts in Quebec, interventions aimed at personal level protection, source reduction or reduction of circulating levels of virus are most appropriate over habitat modification interventions and other forms of vector control and also under the higher transmission risk scenarios described in this study. These results are in agreement with the management options currently implemented in Quebec and elsewhere in North America although other forms of vector control (such as the use of adulticides) have been employed elsewhere in North America under high levels of WNV transmission [5,52].

Limits

It must be clarified that the MCDA approach is based on a socio-constructivist paradigm and that the validity of results is not based on strict reproducibility of results, but rather representativeness of society or relevant group of experts. The validity is also intimately tied to the coherence and transparency of results that are modeling a complex system. There are limits inherent in the choice of stakeholders, but the stakeholders chosen in our

exercise were meant to be relevant to the dimensions at stake within the decision problem. In our example, as a first consultation, stakeholders from public health, wildlife and environmental management responded to our invitation to participate in this exercise. These stakeholders were representative of real-life management in the context of the study (small province where such files are managed by no more than 10-12 people) although many participants were indeed involved in previous WNV outbreaks. It is likely that given a different set of stakeholders, values expressed would be different,

With regards to interventions, from our initial stakeholder validated list, four interventions were found to currently lack sufficient data for evaluation (*use of lethal ovitraps*, *reduction in abundance of the main animal reservoir species*, *modification of habitat to reduce host reservoir species*, and *increasing biodiversity at the peridomestic level)*. While MCDA methods exist to deal with missing data (Greco et al., 2000), these were not explored in the current study to avoid speculating on their efficacy and acceptability. Future models should explore these interventions as data becomes available.

The exploration of multiple scenarios in the models did not yield very different rankings. While some differences in stakeholder weights were observed, convergence of stakeholder values was seen under scenarios of increased transmission severity; however, this did not strongly impact rankings. Many of the stakeholders have been working together on WNV related projects for a number of years which may in part explain the observed homogeneity in responses. A recommendation for future studies would be to include a more diverse group of stakeholders including, amongst others, front line clinicians responsible for providing care to the general population and members of the general population themselves to examine the potential variation in responses. Furthermore, to reduce workload, to explore low and high transmission scenarios

first and if variations are found, to follow-up with medium transmission scenarios analyses where warranted.

Intervention evaluations were not re-assessed under the different scenarios. While many of these evaluations would likely not have changed, the social impact related evaluations might have with potential effects on rankings. However, no data were available to document this change for the current evaluation. An exploration of these and other potential changes to evaluations under different transmission scenarios in future studies may be warranted.

The PROMETHEE algorithm used in the ranking process provides a relative position for ordered interventions, therefore while general observations can be taken away from this analysis, such as individual preventive measures being preferred over regional-level interventions, the actual ranking results are valid only for the current model. In other words, middle or bottom ranked interventions should not necessarily be dismissed as being “poor”, rather they are less favoured over the top ranked interventions in the current model but still remain viable options to explore in future models or analyses as new options and information become available. Overall “poor” interventions, known to be so at the outset should not be included in the model in the first place. For this reason, it is worthwhile to explore specific subsets of interventions to further deepen our understanding of why one intervention may outperform another.

Conclusions

While integrated vector management is often the primary recommendation for VBZD control [18,19,54], multicriteria decision analysis (MCDA) can be used to further refine the selection of complementary interventions for a VBZD management programme. MCDA can integrate cost-benefit analysis type information and other categories of concern including social

acceptability and animal and environmental health concerns. Additionally, the use of scenarios enables the examination of trade-offs between intervention performance and acceptability under different conditions.

The MCDA approach provides the opportunity to not only offer an informed recommendation to decision makers, but also an opportunity to build a shared understanding of the decision problem between different disciplines and sectors thereby increasing adhesion and support of all final recommendations. Further diversifying the stakeholder composition to include various representatives of society can also contribute to this process and should be explored in future projects.

Decisions are ultimately political but must be informed and supported by the best available evidence. While the explicit ranking of possible interventions often represents the main management objective driving a comparative assessment of interventions, the rigorous MCDA process in itself provides a framework to explicitly deconstruct stakeholder expressed priorities, rendering the decision-making process more transparent and arguably richer in its ability to document trade-offs and differing perspectives.

This project showed how a vector-borne and zoonotic diseases (VBZD) management model can be created to assess intervention options for the management of West Nile virus (WNV) at both the individual- and regional-levels taking into account currently available evidence now and under future potential scenarios of climate change. The results confirm that prevention of WNV via individual-level prevention measures such as well maintained window screens, in conjunction with source reduction regional-level interventions, such as larvicides, were top ranked interventions consistent with expressed stakeholders' perspectives and in-line with currently stated WNV management objectives in the province of Quebec. Given the depth of both the model building exercise and

broad similarities in approaching public health interventions for VBZD, we conclude that this current WNV model is likely useful as a base starting point for the analysis of other mosquito-borne diseases. Further work is warranted to better understand and clarify decision making mechanisms and determinants leading to selecting effective public health interventions for other VBZD now and under climate change.

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CHAPTER 6

CAN MALARIA MANAGEMENT BE IMPROVED USING A PARTICIPATORY MULTI-STAKEHOLDER DECISION AID APPROACH WITH LOCAL STAKEHOLDERS?**

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Abstract

Background: Malaria remains one of the major causes of morbidity and mortality in Burkina Faso, particularly in children under 5. Although many public health strategies have been proposed, Burkina Faso and other African countries continue to struggle to control this disease. This article examines the use of a multi-stakeholder multi-criteria decision aid process to help prioritize malaria intervention strategies by means of a participatory approach allowing for the identification and discussion of local stakeholder concerns. This method offers an opportunity to align appropriate interventions given available evidence and stakeholder values in order to contribute to improved malaria management.

Methods: A participatory multi-stakeholder approach was used with a multi-criteria decision aid (MCDA) process. Discussions were held with local stakeholders in Burkina Faso to foster awareness and understanding of local concerns and interventions of interest for malaria management. Using a previously developed disease intervention model, local concerns expressed as criteria were integrated into the model and weighted to reflect local values. These weighted criteria were thereafter used to prioritize a set of potential malaria interventions.

Results: A list of potential individual- and regional-level interventions were identified by stakeholders. Concerns related to malaria management in Burkina Faso were also identified. The resulting categories of concerns in descending order of importance were “public health”, “operations”, “economics”, “social impacts” and “animal and environmental health”. The effect of combining prioritized concerns and regional interventions is illustrated with a pilot ranking of potential malaria interventions that integrates local perspectives.

Conclusions: Cost-effectiveness analysis frequently drives intervention financing decisions; however, it generally examines only one part of the question, what is the most effective measure to reduce infection while maximizing cost? Our study demonstrates that concerns beyond cost-effectiveness alone are held by stakeholders and offer insights into the depths of complexity of malaria management. These include the burden born by individuals and family, sustainability, and public awareness. These additional concerns should be considered in order to improve long term success, adherence and adoption of planned intervention strategies. Participatory decision aid approaches can help achieve this by providing opportunities for rich knowledge exchange and problem structuring between stakeholders. Given the vast number of players involved in disease management in a developing country setting, multi-actor collaborations across NGOs, local government and community are crucial and can be facilitated with a participatory decision aid approach.

Keywords: Malaria management, participatory decision aid, multi-criteria decision analysis

Background

Despite the existence of prevention and treatment options, malaria remains a major cause of mortality in Burkina Faso, especially in children under 5 years of age [1–3]. Malaria is a mosquito-borne disease where symptoms can range from mild fever and chills to severe complications including organ failure and death [4]. Many preventive and control strategies exist to manage the disease including individual preventive behaviours such as the use of long-lasting insecticide-treated nets (LLIN), treatment by means of artemisinin-based combination therapies (ACTs) and vector targeted control measures such as

indoor residual spraying (IRS), yet Burkina Faso and many other African countries experience endemic transmission of malaria and struggle to control and eliminate the disease [1].

Over the years, ambitious global plans have been launched aiming to control and eliminate malaria with notable progress made in reducing global mortality rates in various countries including interruption of local transmission in Argentina, Georgia, Kyrgyzstan, Oman, Syrian Arab Republic and Uzbekistan where zero indigenous cases of malaria were reported in 2014 [5]. Nevertheless, the burden of cases and deaths remains highest among African countries [5]. Malaria is classified as having stable but high endemic transmission in Burkina Faso where it is the leading cause of morbidity and mortality in children under 5 and 2nd leading cause of mortality for all ages in the country [6, 7]. Burkina Faso continues to struggle with poverty and development, (ranked 183 out of 188 countries in the United Nation's 2015 Human development Index). Two-thirds of the country's malaria funding has generally been covered by external and out of pocket expenses [8, 9] and this funding continues to be unstable and low [10].

The most recent strategy, the Global Technical Strategy for Malaria 2016-2030, is a 15-year plan aiming at further control and elimination of the disease where the core WHO-recommended interventions include vector control, chemoprevention, diagnostic testing and treatment [11]. It is however reported that significant ongoing and long-term financing will be needed to fund these interventions at large scales in order to reach planned control and elimination targets [5].

Economic and health burden based tools have often been used to assist in the prioritization of health interventions [12, 13]. While health burden based studies are interesting and important in terms of providing relative and comparable portraits of health contexts between countries and regions, they

obscure important variations and the significance of these through the local social, cultural and economic values of different regions. Furthermore, while cost-effectiveness is important, it is not a guarantee of equitable allocation [14]. Multi-criteria decision aid (MCDA) tools are a complementary approach that have shown promise in helping to prioritize intervention management decisions by offering an opportunity to align interventions with stakeholder priorities [15–17], however, this approach has not yet been explicitly explored in the context of malaria management. Given that considerable percentages of global funding to combat infectious diseases and malaria in particular stem from external sources (78% of malaria programme funding was from international funds in 2014 [6]) where return on investments (or progress) is an important consideration in the decision to donate, careful prioritization of potential intervention strategies is a necessity [18]. This study explores the applicability of a multi-stakeholder, multi-criteria decision aid process in helping to prioritize malaria intervention strategies by means of a participatory process in order to identify local stakeholder concerns and help select the most effective and acceptable interventions in accordance with these concerns. This method offers an opportunity to align the most effective interventions given available evidence and stakeholder values in order to contribute to improved malaria management. This study adapted an existing mosquito-borne disease decision aid model developed for West Nile virus management in the province of Quebec, Canada and discussed necessary modifications with local stakeholders in Burkina Faso in order to evaluate its potential applicability for malaria management in this context. Although the primary goal in this study was to evaluate the adaptability of a previously developed model in the Burkina Faso context, it was not possible to evaluate final end utility of the model with the current study design. Nevertheless, in assessing the adaptability of our model in this setting, we have gained insights on the utility of such an approach in this context.

Methods

A participatory multi-stakeholder approach was used to adapt and assess a previously constructed multi-criteria decision aid (MCDA) model for the management of West Nile virus [19] to a context of malaria management in Burkina Faso in consultation with local stakeholders. West Nile virus is a mosquito-borne disease that can cause febrile illness and general muscle weakness that is currently endemic to several countries, including Canada [19]. Although the two diseases, West Nile virus and malaria, are very different in terms of infectious pathogen and symptoms elicited, both are mosquito-borne diseases, with a potential for overlap with regards to mosquito prevention and control strategies (e.g. vector control efforts and human preventive behaviour strategies).

MCDA is a systematic, transparent and explicit process that can combine available evidence with stakeholder values to support decision-making [20]. The structured MCDA process enables the assessment of identified interventions over a list of evaluation criteria [21]. For the current study, stakeholders from organizations involved in malaria control and water development projects with backgrounds in entomology, environmental management and public health were invited to participate in focus group discussions held in Ouagadougou, Burkina Faso in February 2015. Consultations were held to discuss appropriate decision criteria and interventions for the management of malaria using the previously constructed West Nile virus model structure as the basis for discussion. Discussions were recorded to assist in translation of conceptual ideas expressed by stakeholders regarding specific concerns and interpretation of these into criteria. Following the identification of appropriate decision criteria and potential interventions, stakeholders were asked over the following weeks to assign weights to the identified criteria in order to translate their conceptual value system into quantitative numbers. A Microsoft Excel spreadsheet tool was used

for the weighting exercise and stakeholders were asked to distribute 100 points across the list of criteria included in the model with higher point allocation indicating higher importance of a criterion. Following this, a subset of identified regional interventions was assessed using existing peer-reviewed evidence and measurement scales agreed upon by stakeholders. A keyword search was conducted to identify studies from Burkina Faso and West Africa pertaining to selected interventions. In general, where multiple studies were found, the findings reinforced one another and facilitated the broad characterization of interventions on the measurement scale (see Appendix 5 for measurement scales). More difficulty was encountered with economic costs where estimates often varied from study to study. Here an appreciation of the relative costs of interventions was used to assess relative costs guided by identified studies reporting on this (see Yukich et al., 2008, Morel et al., 2005, White et al., 2011, Laxminarayan et al., 2006, Fillinger & Lindsay 2001, Goodman & Mills 1999, Goodman et al., 2004 and De Allegri et al., 2010 from supplemental references). A pilot prioritization (i.e. ranking) of interventions was carried out over the identified criteria by the researchers using multi-criteria decision analysis with the PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) [34] in visual PROMETHEE software (version 1.4.0.0). The protocol for this project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (Comité d'éthique de la recherche en santé, CERES) (certificate number 14-025-CERES-D) and by the Comité d'éthique pour la recherche en santé in Burkina Faso (Deliberation number 2015-02-019) prior to commencement of the study. All participants gave informed written consent for inclusion prior to participation.

Results

Stakeholders and interventions

Fifteen out of thirty-two invited stakeholders agreed to participate in the discussions held in Ouagadougou, Burkina Faso in February 2015, at facilities provided by the Université Aube Nouvelle. Stakeholders included individuals from the national program against malaria (PNLP), the national research and training center for malaria (CNRFP), national disease control organization, Operational planning, regional health authorities, mosquito control operations and independent university researchers. During discussions, an extensive list of potential individual level and regional level interventions were identified by stakeholders. These interventions included currently recommended WHO interventions as well as potential alternatives. This resulted in sixteen individual level interventions targeting personal protection and source reduction type interventions (Table XXVI) and seventeen potential regional level interventions targeting humans, vectors and other types of interventions (Table XXVII).

Table XXVI. Individual-level interventions considered for managing Malaria in Burkina Faso

Code	WHO[+]	Interventions	Description
I1		Use of mosquito repellent	Ex.: containing DEET, p-menthane-3,8-diol applied to skin
I2		Use of domestic insecticides	Ex.: aerosols, mosquito coils, etc.
I3		Use of alternative technologies	Ex.: automatic insecticide dispensers, electric traps, etc.
I4		Reinforcing the immune system	Education and balanced nutrition to enhance immune system
I5		Use and inspection of window screens	Install and inspect integrity of screens on windows and doors
I6		Human vaccination[#]	Alternative in development
I7		Wearing insecticide treated clothing	Insecticide treated clothing (Permethrin treated)
I8	*	Sleeping under an insecticide treated bed net	Use of deltamethrin or Permethrin treated bed nets
I9		Use of alternative mosquito repellents	Ex.: Neem creams, FASO soap, etc.
I10		Use of traditional plants to repel mosquitoes[*]	Ex.: drinking specific teas to help repel plants
I11		Use of air conditioners or fans	
I12		Prevention by anti-malarial medication	Chemoprophylaxis
I13		Home treatment with traditional plants[*]	Plants used vary following consultation with traditional healers. See (Gansané et al., 2009; Sanon et al., 2003a) for examples of plants used.

Code	WHO+	Interventions	Description
I14		Home treatment with pharmacy bought medication	(Not necessarily ACTs)
I15		Private indoor residual spraying	Hiring of private company to spray indoors and outdoors around property
I16		Improving sanitation of domestic habitats	Including the eliminating peridomestic larval sites

* Interventions added following discussion with stakeholders
# Interventions in development, not currently implementable
+ WHO recommended strategy

Table XXVII. Regional-level interventions considered for managing Malaria in Burkina Faso

Code	WHO+	Interventions	Description
INT01		Modification of larval sites (both natural and artificial)	Ex.: water banks, swamps, marshes,
INT02	(*)	Larval source management (LSM)	Combinations of habitat modification and larval management via BTI or insecticides
INT03	*	Indoor residual spraying (IRS)	
INT04		Use of genetically modified mosquitoes #*	
INT05	*	Free bed net distribution and awareness campaign (LLINs)	Outreach and awareness raising campaign accompanied by free distribution of Deltamethrin or Permethrin treated nets
INT06		Human vaccination #	Alternative in development
INT07	*	Use of rapid diagnostic tests and artemisinin based therapies (RDTs + ACTs)	
INT08		Reinforce health agent skills and competencies	
INT09	*	Targeted intermittent treatment for vulnerable groups (IPTp)	Ex.: pregnant women and infants
INT10	*	Seasonal malaria chemoprophylaxis (SMC)	Monthly chemoprophylaxis for children 3-59 months
INT11		Promotion, support and valorisation of research results*	
INT12		Promotion, support and valorisation of traditional medicine *	
INT13		Protection of the environment and traditional plants *	
INT14		Enhanced training and tools for community-based volunteers to ensure awareness and proper treatment via ACTs following RDTs	
INT15		Strengthening collaborative links and integration with nutrition programs and other diseases *	
INT16		Development of inter-sectoral collaboration*	
INT17		Information and educational campaign	Informational health education campaign on the use of preventive strategies (e.g. bed nets)

* Interventions added following discussion with stakeholders
# Interventions in development, not currently implementable
+ WHO recommended strategy

Criteria and weights

Criteria representing issues and concerns that had been raised with regards to West Nile Virus management in Canada were reviewed by stakeholders in Burkina Faso. A majority of these criteria were retained and adapted for the Burkina Faso malaria model. The criterion pertaining to the proportion of circulating virus in the animal reservoir was removed (as the only reservoir for human malaria is humans) and a criterion pertaining to the potential of an intervention to raise population awareness about the disease was added. Additional details were added to the economic criteria to include costs incurred by the government, costs born by individuals and families and also external donors such as non-governmental organizations (NGOs). The final list of criteria for the Burkina Faso malaria model included nineteen criteria (Table XXVIII) distributed across the following five categories: *"Public Health criteria", "Social Impact criteria", "Animal and Environmental Health criteria", "Economic criteria" and "Strategic and Operational criteria"*.

Table XXVIII. Criteria for evaluating Malaria interventions in Burkina Faso

Category	Criteria	Description
Public Health Criteria (PHC)		
	PHC1 - Incidence reduction	Reduction in incidence of human cases
	PHC2 - Entomological risk reduction	Reduction of entomological risk
	PHC3 – Differential diagnostic*	Ability to discern between diseases
	PHC4 –Physical health impact	Impacts to human physical health
	PHC5 - Mental health impact	Impacts to human mental health
	PHC6 – Social equity	Impact on social equity
	PHC7 – Proportion affected	Proportion of population that benefits from the intervention
Social Impact Criteria (SIC)		
	SIC1 – Public acceptance	Level of public acceptance
	SIC2 – Impact to credibility	Impact to confidence in and credibility of organisation in charge
	SIC3 – Public awareness*	Knowledge and awareness of disease and recognition of symptoms
Animal & Environmental Criteria (AEC)		
	AEC1 – Animal health impact	Impact on animal health
	AEC2 – Environmental impact	Detrimental effect of intervention on environment (e.g. pesticide contamination)
Economic Criteria (ECC)		
	ECC1 – Government cost	Cost to the government
	ECC2 – Individual and family cost#	Cost to individuals and families sector
	ECC3 – Cost born by external donors#*	Cost to external donors (e.g. NGOs, etc.)

Category	Criteria	Description
Strategic & Operational Criteria (SOC)		
	SOC1 - Delay	Delay before appearance of desired effect
	SOC2 – Complexity	Institutional and operational complexity of the intervention
	SOC3 – Sustainability	Sustainability of the intervention
	SOC4 – Other policy impact#	Impact on other public policies

* Criteria added following discussion with stakeholders
# Criteria modified following discussion with stakeholders
Note: interventions are listed in italics when referenced throughout the text to distinguish from "criteria" which are listed in "quotes".

Ten of the participating stakeholders (67%) completed the weighting exercise and the weight attributions by stakeholder are shown in Table XXIX. The average criteria weight values by category are shown in Fig 11. The weight span for categories was large among stakeholders (ranging from 20 to 37 point differences in some instances) suggesting a diversity of perspectives among consulted stakeholders with regards to the relative importance of criteria. Criteria in the "Strategic and Operational criteria" category as well as those in the "Public Health criteria" category had the largest weight span while the criteria in the "Social Impact criteria" and "Animal and Environmental Health criteria" categories had the smallest weight span. The categories of "Public Health criteria", and "Strategic and Operational criteria" received the highest weight average for the group of stakeholders followed by the "Economic criteria", "Social impact criteria" and "Animal and environmental health criteria" categories respectively.

Table XXIX. Stakeholder weights by criteria in the malaria MCDA model for Burkina Faso

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
PHC-01	6.25	20	2	7.5	3.2	5	7	2	15	11
PHC-02	3.75	0	2	5	10	5	6	0.3	7	0
PHC-03	1.25	8	6	2.5	3.2	3.75	10	5	9	0
PHC-04	2.5	2	0.5	1.25	14.8	1.875	8	0.4	0	6
PHC-05	2.5	4	0.5	1.25	1.2	1.875	3	0.7	0	6
PHC-06	3.75	2	1	1.25	1.2	3.75	4	0.1	0	6
PHC-07	5	4	3	6.25	6.4	3.75	7	1.5	7	6
SIC-01	10	18	2	1	6.5	8	5	12	8	7
SIC-02	5	3	4	2	2.75	4	3	5	3	0
SIC-03	5	9	4	7	15.75	8	2	5	5	7
AEC-01	6.25	1	3	3	3.5	5	4	2	4	6
AEC-02	18.75	9	2	12	3.5	5	6	6	8	6
ECC-01	5	2	10	5	10.8	7.5	7	15	2	0
ECC-02	15	2.5	10	14	7.6	12.5	7	13.5	12	14
ECC-03	0	0.5	5	1	1.6	5	1	1.5	3	0

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SOC-01	1	4.5	2	12	1.2	5	5	12	5	10
SOC-02	1.5	3	14	7.5	1.04	4	4	9	5	5
SOC-03	5	4.5	25	6	2.32	6	6	6	4	5
SOC-04	2.5	3	4	4.5	3.44	5	5	3	3	5

S1-S10 Indicate stakeholders 1 through 10 having participated in criteria weighting exercise

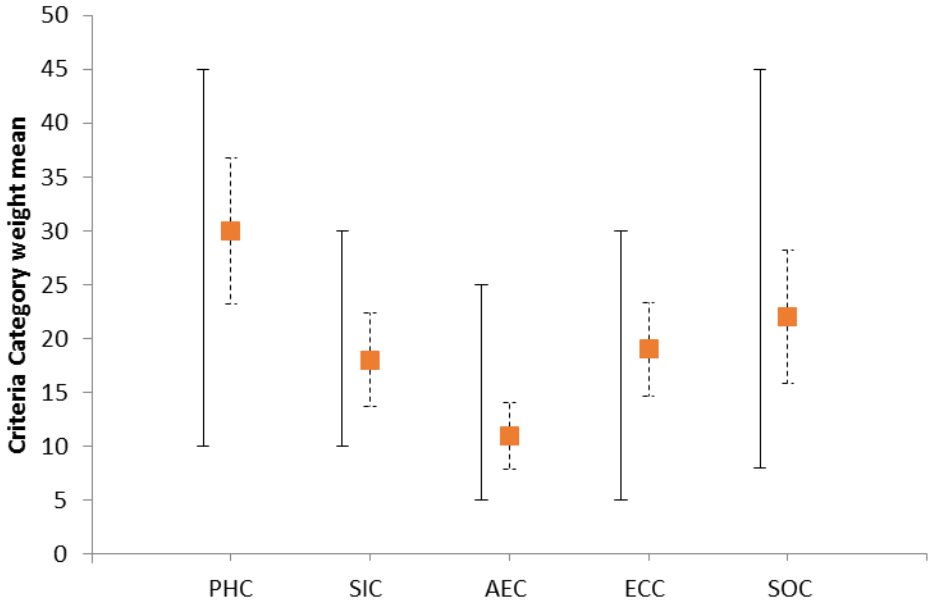

Figure 11. Average stakeholder weights by category for the malaria MCDA model in Burkina Faso

Criteria categories are shown along the X axis and average weights by category are shown along the y axis. Solid bars indicate the stakeholder assigned weight ranges for criteria categories. Square markers indicate criteria weight mean for the specific category and dotted lines indicate the 95% confidence interval around the mean. Criteria category Legend: PHC: Public Health Criteria; SIC: Social Impact Criteria; AEC: Animal and Environmental Health Criteria; ECC: Economic Criteria; SOC: Strategic and Operational Criteria.

Pilot prioritization of interventions

To illustrate the effects of local values on the model, five of the WHO core recommended interventions, namely distribution of free bed nets (LLINs), intermittent treatment for pregnant women (IPTp), seasonal malaria chemoprevention for children (SMC), use of rapid diagnostic tests and artemisinin based therapies (RDTs + ACTs) and indoor residual spraying (IRS), and one WHO

supplemental intervention (larval source management (LSM)) were assessed using evidence from the literature (Table XXX). Where possible, studies from Burkina Faso were used to evaluate intervention scores, however in many cases, studies from other countries were used. Costs in particular were assessed based on a relative interpretation of a number of cost-effectiveness studies [24–31] for malaria interventions with large variations in results. Not all interventions may be appropriate at all scales and further validation will be required to assess scalability of interventions. Here the relative cost between interventions (including delivery costs) was of most interest and was captured with LLINs, IRS and LSM evaluated with an order of magnitude significantly higher than IPTp and SMC. Costs were also assumed to be primarily born by external donors and thus costs to local government were evaluated much lower. A list of references used to evaluate interventions is included in the supplementary material. The relative importance of assessed interventions combined with stakeholder assigned weights was analyzed to produce a ranking of regional interventions (Table XXXI).

Table XXX. Evaluated malaria interventions

	INT02	INT03	INT05	INT07	INT09	INT10
PHC1	3	3	3	0	3	3
PHC2	3	3	3	0	0	0
PHC3	0	0	0	1	0	0
PHC4	1	2	2	0	1	1
PHC5	1	1	1	0	0	0
PHC6	0	1	-1	1	1	1
PHC7	3	1	3	2	2	2
SIC1	1	2	2	1	1	1
SIC2	0	0	0	0	0	1
SIC3	0	0	1	1	0	0
AEC1	1	2	2	0	0	0
AEC2	1	8	8	0	0	0
ECC1	1	1	1	1	1	1
ECC2	0	0	0	1	0	0
ECC3	3	3	3	3	2	2
SOC1	2	1	1	0	1	1
SOC2	3	3	2	3	2	2
SOC3	1	0	2	0	0	0
SOC4	-1	2	1	-1	-1	-1

Table XXXI. Group ranking of the regional-level management interventions for malaria in Burkina Faso.

Code	Intervention	Rank	Net Flow
INT09	Targeted intermittent treatment for vulnerable groups (pregnant women) (IPTp)	1	0.0806
INT05	Free distribution of bed nets and awareness campaign (LLINs)	2	0.0802
INT10	Seasonal malaria chemoprevention (SMC)	3	0.0617
INT02	Larval source management (LSM)	4	0.0433
INT07	Use of rapid diagnostic tests and artemisinin based therapies (RDTs + ACTs)	5	0.0202
INT03	Indoor Residual Spraying (IRS)	6	-0.1021

The top three identified interventions in this model were: Targeted intermittent treatment for vulnerable groups (IPTp), Free bed net distribution and awareness campaign (LLINs), and Seasonal malaria chemoprophylaxis (SMC) with IPTp and LLINs nearly tied in their evaluation scores. Larval source management (LSM), use of rapid diagnostic tests and artemisinin based therapies (RDTs + ACTs), and Indoor residual spraying (IRS) were least favored. Examination of intervention profiles (Fig 12) showed all interventions to have mixed performance overall with no single intervention performing extremely well over all criteria and conversely no single intervention performing very poorly over all criteria. The top four interventions had better performance ratios (good vs poor) over a majority of the criteria compared to the bottom three interventions.

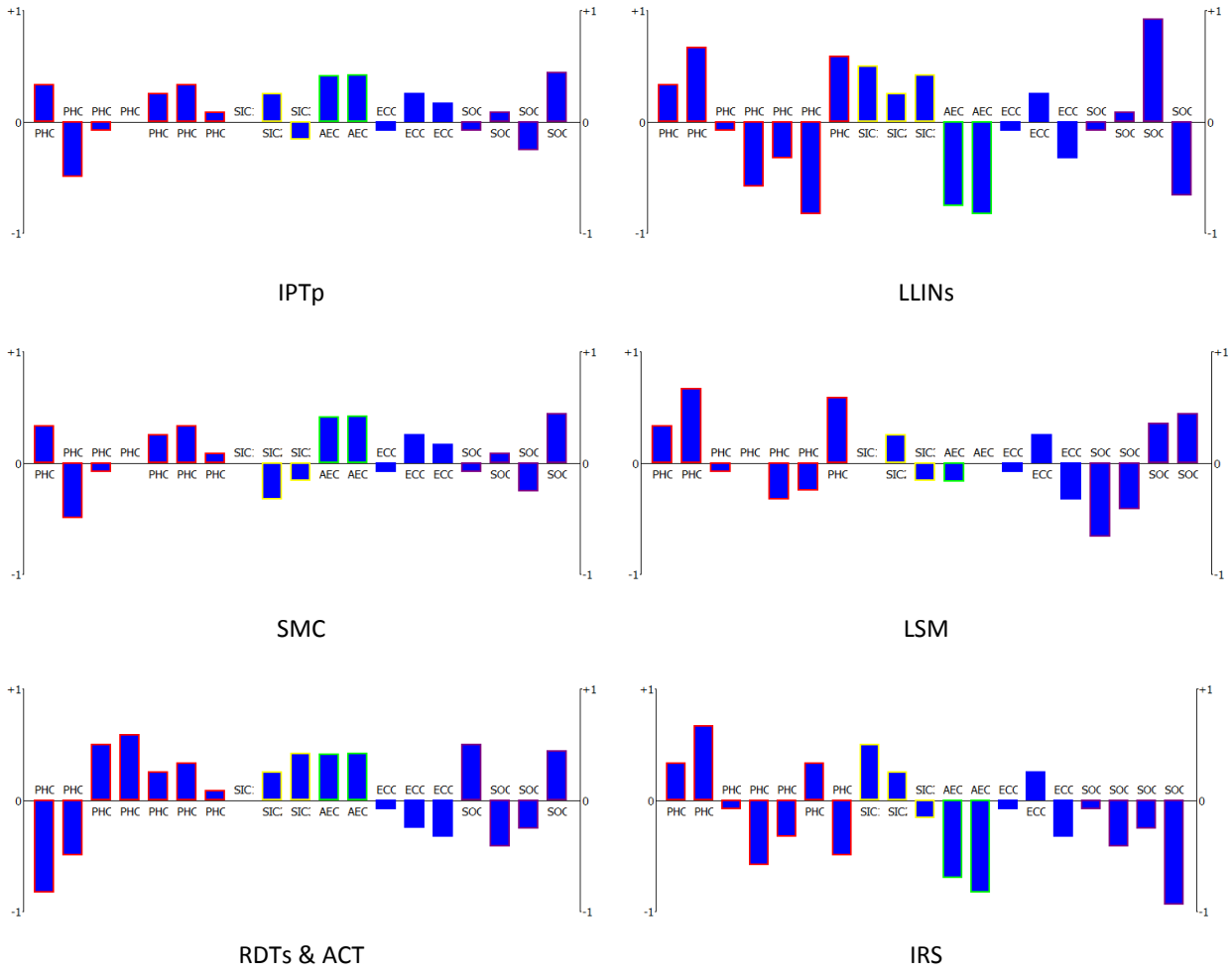

Figure 12. Intervention profiles in the malaria MCDA model in Burkina Faso

Profile bars represent the relative performance of interventions on each of the retained criteria. Bars above the zero-horizontal axis represent the flow score accounting for the number of times the intervention outperformed compared interventions over each specific criterion. Conversely, bars below the zero-horizontal axis represent the times the intervention was outperformed by compared interventions. LLINs – long lasting insecticide treated nets; IPTp – intermittent preventive treatment; SMC – seasonal malaria chemoprophylaxis; RDTs & ACT – Rapid diagnostic tests and artemisinin based therapy; LSM – larval source management; IRS – indoor residual spraying

Discussion

Regional interventions

In this analysis, we showed how existing evidence on interventions can be combined with stakeholder values to produce an evidence-informed prioritization of interventions. In this particular case, literature evidence for WHO recommended interventions were combined with criteria weightings made by stakeholders residing in Burkina Faso in order to assess the most effective and acceptable interventions for malaria management. Among the assessed regional strategies for malaria management, a slight preference was observed for bed nets, intermittent treatment for pregnant women (IPT) and seasonal chemoprophylaxis. Interestingly, although often in combination in the field [32], Free bed net distribution and awareness campaign and indoor residual spraying (IRS) were found to be most and least preferred interventions respectively in this analysis. While IRS is among the WHO recommended strategies and a pilot project was carried out in Burkina Faso by the USAID program to test implementation of this strategy at a small scale, this intervention has not been scaled up to the national level in Burkina Faso due to insufficient funds to do so [9]. The PROMOTHEE approach to intervention ranking does not have stakeholders directly rank interventions, rather stakeholders are asked to weight criteria (i.e. concerns) only and intervention factual performance is assessed based on available evidence. As a result, these analyses should not be interpreted as implying that bed nets are inherently better than indoor residual spraying as a strategy, but rather that given reviewed evidence pertaining to concern over increasing insecticide resistance [33, 34], concerns over funding sustainability [34] and stakeholder expressed concerns pertaining to exposure to pesticides [35], there was a preference for bed nets as an intervention strategy. Given the complexity of the epidemiology of malaria and many existing challenges to

successful control and elimination, what is ultimately more practical to consider is how interventions deemed effective might best be combined in order to implement comprehensive strategies for control and elimination coherent with local values and concerns.

Examination of the intervention profiles suggests that many of the assessed interventions are complementary and should be combined where possible to increase protective and control efficacy of strategies. For example, from Fig 12 we can observe how free bed net distribution and awareness campaigns (LLINs) appear highly compatible with Targeted intermittent treatment for vulnerable groups (IPT) and Seasonal malaria chemoprophylaxis (SMC), where when combined, these interventions perform very well over five out of the seven "Public Health" criteria ("Incidence reduction", "Entomological risk reduction", "Mental health impact", "Social equity" and "Proportion affected"), all "Social Impact" and "Animal & Environmental Health impact" criteria, relatively well over the last two "Economic" criteria and generally well over two out of the four "Strategic and Operational" criteria. Adding the Use of rapid diagnostic tests and artemisinin based therapies (RDTs + ACTs) intervention would further contribute to improved performance over the entire set of "Public Health" criteria by contributing to improved "Differential diagnostic" and "Physical health impact" as well as improving the "Delay" criterion from the "Strategic and Operational" category. While this combination of interventions may appear relatively intuitive, what stands out from this analysis is how MCDA can be used to systematically analyze various subsets of complementary interventions in order to construct a robust and locally adapted strategy that targets important disease management objectives while addressing stakeholder identified concerns.

Concerns and Criteria

A number of the concerns raised by stakeholders surrounding management of malaria were similar to those previously identified in the management of West Nile virus [19] such as, for example, the importance of "incidence reduction of the disease" and "reducing the entomological risk" while also "minimizing adverse effects on physical and mental health", aiming to "ensure high public acceptance", while "minimizing costs" and "complexity", "delays" and "adverse effects on animal and environmental health". However, in addition to this, many context specific concerns were raised in Burkina Faso following discussions with stakeholders. These included the importance of an appropriate "differential diagnostic" prior to treatment, assurance of "use and sale of quality medication", "raising of public awareness about the disease", "consideration of costs borne by individuals and their families" as well as "costs borne by external funders including NGOs" and awareness to seek out the "potential for synergies with existing policies or programmes". Additionally, concerns over the growing threat of "insecticide and drug resistance" were also raised. Contextual explanations were required to clarify proposed criteria and improve their applicability to the malaria context in Burkina Faso. For example, the notion of adverse mental health effects at first did not receive any traction with Burkinabe stakeholders. However, once this was discussed more thoroughly with stakeholders to clarify that it could include notions such as claustrophobia when using bed nets; this was recognized as being a potential consideration of interest and the criteria was retained. There was explicit recognition that while bed nets are a recommended preventive intervention, there are challenges with their effective and sustained use. Household ownership of bed nets in various regions of Burkina Faso has been recorded to be relatively high following previous mass distribution campaigns [36]; however, net ownership does not guarantee its proper use and a number of studies in Burkina Faso and other African countries have identified various reasons why net use might be inconsistent at various

times of the year including varying sleeping arrangements, heat and general discomfort [37–39].

The concern around differential diagnostic is an important issue that is beginning to receive attention. According to recent studies in the region, many cases of fever are presumptively treated during the rainy season with anti-malaria drugs which can contribute to drug resistance [40, 41]. This was the recommended practice by the WHO until recent evidence suggested the growing risk of drug resistance; however, while official policy has changed in Burkina Faso, in practice this is still a problem [9]. This concern was raised by stakeholders as an issue of importance at multiple levels ranging from doctors who frequently treat presumptively during the rainy season to individuals who frequently self-medicate fevers during the rainy season. Only a very small proportion of cases are actually seen by the health care system, and then generally only when alternative courses of action have failed [3, 42]. Additionally, substandard quality or counterfeit medication further complicates efforts to control the disease [3, 43, 44]. While efforts and innovative ideas are being developed to reduce them [45], the existence of informal drug markets and poor quality or counterfeit anti-malaria medication is a major obstacle to effective malaria elimination that is undermining global control efforts, further increasing the risk of emergence and spread of resistant malarial parasites and contributing to the burden of avoidable morbidity and mortality [46–49].

Much discussion was held around the importance and heavy reliance of the country on external funding to support the implementation of many WHO promoted interventions and heavy costs borne by individuals and families in caring or obtaining treatment for malaria especially the more complicated cases. In discussions related to funding, concern was expressed regarding the need to improve coordination and find optimization opportunities between the numerous local and foreign actors working towards malaria and other infectious disease

control activities in the country. Stakeholders suggested the existence of potential opportunities for increased coordination between health interventions for example by means of integrated malaria vector control activities with other disease control activities [50] or coupling of malaria interventions with other health interventions [51] such as intermittent treatment for pregnant women (IPTp) during antenatal visits or administration of seasonal malaria chemoprophylaxis (SMC) during existing vaccination program schedules. The coordination of the large number of health and development aid actors in Burkina Faso was an important and ongoing challenge raised by stakeholders on the road towards malaria control and elimination [9, 52].

Further insights

Beyond the MCDA enriched assessment of core WHO interventions, a number of further insights were made possible during this study as a result of the participatory approach used. This included comprehensive lists of individual- and national-scale proposed interventions produced by stakeholders that extend past those interventions recommended by WHO alone. Stakeholders were well versed in the core WHO recommended interventions (LLINs, IRS, IPTp, SMC, RDTs & ACTs) and supplementary interventions (LSM) which had been proposed following a review of the literature. However, in addition to this, stakeholders proposed the addition of a number of lesser known options such as the use of traditional plants to repel mosquitoes (in various forms such as creams or teas for example) and as rapid diagnostic tests as well as the valuing of traditional healers and environmental spaces to protect traditional plants for preventive and medicinal purposes. Traditional plants and medicine are frequently used in many areas of Burkina Faso alongside western medicine [53] and some have demonstrated repellent [54, 55] or antiplasmodial effects [56, 57]. A comprehensive review of traditional plants and medicine was outside the scope of the current study and therefore not assessed; nevertheless, a case is made for

their consideration. Burkina Faso and other regions have at times experienced extensive drug and diagnostic test stock-outs [58, 59] creating further challenges to adhering to WHO recommendations, and while efforts are being made to make these courses of action universally accessible [27], for many of the country's residents, they remain prohibitively unaffordable [3]. Furthermore, a study by Bisoffi and colleagues in 2010 recommended against adopting a country-wide policy of routine testing prior to administering drug treatment due to the prohibitive costs and possible error rates in accurately detecting malaria in children with rapid tests [60, 61]. Although published evidence may not yet be extensive as to the relative effectiveness of alternative interventions for repellent use, a combination of locally sourced and grown products as supplemental and complementary courses of action to WHO recommended core interventions should be explored in further studies as these could potentially offer sustainable and affordable preventive options that are better aligned with existing local practices and as a result may be more readily adopted and maintained by local communities. These and other interventions were topics that local researchers expressed interest in investigating further, however, due to the financial struggles of the country, researchers expressed frustration regarding a sense of lack of autonomy in selecting research topics. Furthermore, in the cases where research already exists, stakeholders expressed frustration at poor promotion and translation of local research results into practice, a finding that has been previously expressed by Burkinabe researchers [3]. Although contextually different, the erosion of traditional knowledge and practices of Inuit communities in the Arctic has been linked to increased vulnerability and reduced adaptive capacity of these communities to climate change [62]. While development aid decision making is complex, additional consideration should be given to the implementation of interventions which threaten to displace existing ways and knowledge.

This study was not meant to be a formal assessment of malaria intervention priorities for Burkina Faso, but rather meant to assess the applicability of a previously developed model in this new context. In the process of this assessment, this approach has shown how a participative and systematic prioritization approach can contribute towards improved understanding of the issues of concern to stakeholders and improved alignment of proposed interventions with stakeholder values while taking into account available evidence and stakeholder knowledge, experience and concerns in the process. Due to time constraints, a fully iterative MCDA process was not carried out. Instead, elements from a pre-existing WNV model [19] were used and adapted to fit the Burkina Faso context following discussions held with local stakeholders. Had a fully iterative process been carried out, the final model might have resulted in a different set of interventions and criteria. As such, more in-depth discussion regarding the indicators of importance to local stakeholders should be held in the future should a more exhaustive set wish to be constructed. Existing interventions can act on a number of very different indicators (e.g. maternal anemia and birthweight versus child or adult incidence averted versus fatality averted or entomological risk reduction) and therefore direct comparison between these interventions is difficult, however, a refinement to the process with inclusion of these indicators could further provide concerted action towards malaria control and elimination. Nevertheless, the MCDA process and model used in the current study has provided a rich entry point into assessing available evidence and aligning this with existing concerns in order to plan and coordinate sustainable interventions for malaria control.

Conclusions

In this study, we have demonstrated how a participatory process held with local stakeholders can be combined with available evidence to inform

management planning of malaria in a developing context. The multi-criteria decision analysis (MCDA) process used provided an opportunity for rich knowledge exchange between participants who shared experience-borne concerns around known interventions. This included concerns regarding drug and insecticide resistance, research funding and choice of research topics, drug availability and quality, diagnostic capabilities and the need to improve coordination between health actors in the country. Further research should be done to evaluate the practical utility of this approach and fine tune the selection of the most contextually relevant criteria and indicators for the model. In addition to this, further refinements to the model could also include additional epidemiological and ecological specific information to see whether different strategies might be recommended depending on whether planning is intended for management during the dry versus the wet season. Complete eradication of malaria in Burkina Faso and other countries will require continued support of the international community however in lending financial and other support, care and time should be taken to assess local concerns in order to improve harmonization of interventions with the country context and values of its inhabitants. While cost-effectiveness is an important consideration in funding interventions, it should not be the only consideration. Formal participatory approaches, such as the one used in the current study, provide a means to foster shared awareness, consensus, and collaboration between stakeholders while allowing for the integration of multiple concerns (beyond cost-effectiveness alone) and thus offer an opportunity to improve coherent malaria control strategy planning adapted to locally held contexts and values.

List of abbreviations used

ACT – artemisinin-based combination therapies
CNRFP - national research and training center for malaria
DALYs – Disability adjusted life years

IPTp – Intermittent preventive therapy in pregnant women
IRS – indoor residual spraying
LLIN – long-lasting insecticide-treated nets
LSM – larval source management
MCDA – multi-criteria decision analysis
NGOs – Non-governmental organization
PNLP - national program against malaria
PROMETHEE - Preference Ranking Organization Method for Enrichment Evaluations
RDT – Rapid diagnostic tests
SMC – Seasonal malaria chemoprophylaxis
VBD – vector-borne disease
WHO – world health organization
WNV – West Nile virus

Declarations

Ethics approval: The research protocol for this project was reviewed and approved by the Ethical Committee for Health Research of the University of Montreal (CERES)) (certificate number 14-025-CERES-D) and by the Comité d'éthique pour la recherche en santé in Burkina Faso (Deliberation number 2015-02-019) prior to commencement of the study.

Competing interests: The authors declare that they have no competing interests.

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Author's contributions: VH, KS and HC carried out focus groups discussion in Burkina Faso. VH performed the analyses and wrote the manuscript. PM, PG, CC, KS, HC, AR, and JPW contributed to analysis and interpretation of the data and writing of the final manuscript.

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DISCUSSION

Given the considerable health impacts of climate change and anticipated effects on vector-borne disease, there is increasing need to develop robust adaptation strategies to manage vector-borne disease risk under climate change. This thesis aimed to contribute to climate change adaptation research by identifying key concerns and factors of importance in managing vector-borne disease risk. Using a climate change adaptation and vulnerability assessment approach, we examined issues around three key questions: what diseases are we concerned about? Who is most vulnerable and at risk? and what are strategies to manage vector-borne disease risk under climate change? Towards this end, three phases important for vector-borne disease (VBD) management and decision-making were examined: vector-borne disease prioritization (chapters 2 and 3), an assessment of population preparedness against mosquitoes and mosquito-borne disease by means of a survey on current knowledge and practices of the Quebec population with respect to West Nile virus (WNV) (chapter 4), and vector-borne disease adaptation and management strategies using WNV in Quebec and malaria in Burkina Faso as specific examples (chapters 5 and 6). These three phases contribute respectively to elements of impact assessment, vulnerability assessment and adaptation assessment necessary for adaptation research and planning.

Disease prioritization and disease management contexts were examined in two contrasting settings: Quebec (Canada) and Burkina Faso (West Africa). While adaptation to climate change was the primary impetus for the research work, many of the decision-making contexts examined pertain to reconciling existing concerns in a context of change. The approach used to examine this

context is consistent with an evidence-informed approach (Baltussen and Niessen, 2006; Bowen and Zwi, 2005; Ciliska et al., 2008; NCCHPP, 2010) taking into consideration both scientific evidence and stakeholder views and experiences to contextualize the risk. One of the longstanding debates in the climate change literature has been whether to focus on adaptation versus mitigation. The accumulated greenhouse gases (GHG) in the atmosphere to date have now committed us to an unavoidable level of climate change over the next several decades and thus the necessity for adaptation in order to reduce anticipated adverse effects (IPCC, 2007a). However, a new dilemma is sometimes voiced regarding how to reconcile adaptation needs versus existing needs. This body of work lends support to the notion that both can and should be done in parallel. Indeed, one of the most effective means of protecting against climate change impacts involves reducing existing disease risks (Campbell-Lendrum, D., 2015). This discussion aims to analyze the principal findings of the various parts of the research project and discuss their relevance in a context of evidence-informed climate change adaptation research. Chapter specific contributions are summarized in Table XXXII. The significance of these contributions is discussed and contextualized within the broader adaptation research framework in the following sections.

Table XXXII. Summary of knowledge contributions

Chapter	Contributions
Impact assessment and disease prioritization	
2	• Identification of key concerns to consider for disease prioritization under climate change. • Demonstrates the existence of different weights of concern within a population (Quebec) and how these vary based on the intervention-context (e.g. research versus surveillance versus prevention and control) and affect resulting priorities. • Demonstrates how public health and non-public health stakeholder concerns can vary within a population (Quebec) and be reconciled within a same participatory process. • Demonstrates how the degree of shared relative values between groups (e.g. public health and non-public health stakeholders) can be assessed.
3	• Demonstrates how major concerns (i.e. criteria) can be shared across very different regional contexts (e.g. Quebec and Burkina Faso) • Demonstrates how these shared concerns give rise to different priorities as a result of region specific weights and contextualization (e.g. local status of health system, disease epidemiology) • Demonstrates the existence of additional concerns important to consider in disease prioritization beyond those captured by DALYs
Vulnerability assessment and population preparedness	
4	• Provides an update on the current status of knowledge, perceptions and behaviours relative to mosquitoes and WNV in southern Quebec. • Demonstrates how perceptions (including perceived exposure to mosquitoes) differ by region. • Demonstrates how motivations for adopting protective behaviours differ within a population and appear to be primarily driven by perceived exposure to mosquitoes rather than concern for WNV at this time in Quebec. • First examination of individual's sense of responsibility in relation to the adoption of protective behaviours against WNV. • First use of a multiple correspondence analysis to explore population subgroups with respect to preventive behaviours related to WNV. • First demonstration of the existence of different subgroups within a population each with different perceived exposure to mosquitoes, awareness and knowledge of WNV and adoption levels of preventive behaviours. Offers insight into groups to target for market segmentation of public health messaging.
Adaptation assessment and vector-borne disease management	
5	• Demonstrates how a previously constructed Lyme disease MCDA model can be adapted for a different vector-borne disease: in this case, WNV management in Quebec. • Demonstrates how MCDA can be used for WNv planning under different epidemiological scenarios taking into account ongoing prevention and control actions planned in a given season.
6	• Demonstrates how a previously constructed WNV MCDA model can be adapted for a different vector-borne disease: in this case, malaria management in Burkina Faso. • Provides a list of local stakeholder identified individual interventions and a list of stakeholder identified regional interventions. These lists provide avenues for future research where interventions are currently unexplored. Further suggests opportunities to explore the combination of traditional and western knowledge as complementary and supplemental means of providing more sustainable malaria control solutions. • Contributes to unpacking the malaria problem in Burkina Faso by identifying concerns expressed by local stakeholders around the disease and its management. • Provides insight into the depth of complexity of malaria management in this region and cautions as to why cost-effectiveness analysis alone is likely to be insufficient and unsustainable to manage malaria in the region

Analysis of findings

Impact assessments: The need for disease prioritization

Our examination of "what diseases are of concern under climate change?" led us to identify what the key concerns are in prioritizing diseases under climate change. Here in our study, we used a deliberative multi-criteria decision aid (MCDA) approach with stakeholders from diverse disciplinary backgrounds (vector-borne disease, environmental management, biology, medicine among others), including both disease experts and non-disease experts together, in order to identify key concerns in the development of a general model for VBD disease prioritization under climate change in Quebec (Canada). This model was then adapted in Burkina Faso, to assess whether shared concerns exist and examine the effects of these concerns in determining disease priorities in two very different settings. We found that there exists a core set of concerns that emerge with respect to the impact of diseases on human health. This core set of concerns appears to be shared across public health intervention contexts and countries. These concerns include assessing the human health impact of diseases, their current burden, level of social concern, economic costs associated with cases and potential animal and environmental impact. In addition to this, explicit concerns emerge that are context specific. For example, in the domain of public health research, concerns and emphasis are placed on assessing the current level of knowledge of diseases while in surveillance contexts, more emphasis is placed on emergence risk criteria. When these concerns are subsequently weighted in light of the management context, different priorities emerge as might intuitively be expected.

Additionally, we found that regional nuance matters considerably both in terms of the parametrization of the data to reflect the existing epidemiological

context for the region, as well as including and accounting for culturally specific values ascribed by stakeholders to identified concerns. This gives rise to different priorities depending on the region. While this holds intuitive sense, it is important to systematically examine resulting local priorities and not assume shared priorities even if shared concerns exist. Our work significantly contributes to this nuance and contrasts with the Global Burden of Disease (GBD) approach (Murray and Lopez, 2013). While very useful in its own right in terms of facilitating comparisons between countries and regions as well as providing a means to account for both fatal and non-fatal health outcomes (DALYs -disability adjusted life years, see (Murray and Lopez, 2013)), GBD measurement alone should not be used as the sole and final guide for setting local priorities. While regional estimates are calculated within the GBD framework, at a smaller, local scale, further examination of local values and concerns is necessary to ensure the setting of corresponding priorities. Our evidence-informed MCDA approach offers an opportunity to incorporate additionally relevant concerns and experiences which may not be reflected within standardized metrics such as DALYs. For example, while adapting our disease prioritization model with stakeholders in Burkina Faso, the issue of access to treatment and the availability of adequate conditions to treat the disease were raised as additional concerns to consider. This concern reflects local operational realities that are essential to consider in setting disease management priorities. Additionally, the preoccupation and inclusion of international risk perception and funding considerations of NGOs and other non-local funding bodies in the model underscores deeper systemic issues in development settings and an ongoing effect of eroded local autonomy in setting and managing priorities. Hearing from local stakeholders contributes to enriching our understanding of the problem in context and helps us to begin to address the complex nuances inherent to the problem.

Vulnerability assessment: Population preparedness

In examining the question around who is most vulnerable and at risk to vector-borne disease, we assessed current knowledge and practices of residents of southern Quebec to mosquitoes and WNV. Overall, we found knowledge levels of WNV and practices to protect oneself from mosquitoes to be relatively good among residents of the population of Quebec although not necessarily associated with high levels of concern for WNV. Our use of multiple correspondence analysis to examine the structure of our sampled population suggested the existence of at least four subgroups with different factors and levels of preventive behaviour adoption: the 'unaware citizen', the 'unconcerned citizen', the 'mosquito-exposed citizen', and the 'concerned citizen'. Among these groups, we found the first two groups to be most at risk to WNV and mosquito-borne threats as they practiced the least amount of recommended protective behaviours while the later two groups appeared to have good adoption rates of protective behaviours. The identification of different subgroups with different behavioural practices is important to keep in mind in targeting effective public health communication messages. Interestingly, these four groups are analogous in part to Füssel's (2007) hypothetical farmers used to examine impacts and adaptation to climate change. Population segmenting has been explored in social marketing type studies and allows the construction of more tailored messages to more effectively target specific groups (Campo et al., 2012). Knowledge of these types of population subsets, as found in our study, may be useful for crafting more effective adaptation messages to protect against changing mosquito-borne disease risk.

Furthermore, we also examined individual`s sense of responsibility with regards to reducing one's risk of exposure to mosquito-borne disease and found that there is an apparently high level of perceived self-responsibility to protect one's health from mosquito bites and mosquito-born disease risk among sampled

Quebec residents which is not mutually exclusive from a reliance on public health authority to protect health. Adaptation can occur at both public and private levels (Grothmann and Patt, 2005). In our case, public measures would correspond to public health authority adaptation measures while private measures would correspond to personal- or population-level adoption of protective behaviours. A key element in personal adaptation may be tied to an individual's sense of responsibility versus their reliance on public authority adaptation to protect them (Grothmann and Patt, 2005). Though the nature of our results cannot establish causality and are only applicable to populations residing in southern regions of the province of Quebec, our results suggest that the population is proactive in taking charge of their own health protection. Sense of responsibility is considered an important factor for adaptive capacity and our study is the first to examine this concept in relation to the adoption of protective behaviours against WNV.

Adaptation assessment: Managing vector-borne disease

To examine strategies for managing vector-borne disease risk under climate change, a multi-stakeholder, multi-criteria approach was used to construct an evidence-informed MCDA model to assess management strategies for vector-borne disease. For effective adaptation planning around existing and anticipated vector-borne disease threats, there is a need to identify what the key concerns are above and beyond the cost of interventions alone and evaluate management options over this range of concerns. Additionally, it is important to examine current and planned public health strategies in order to assess their ability to address current and anticipated management objectives under intensified transmission. Here both West Nile virus in Quebec and malaria in Burkina Faso were used as illustrative diseases to examine disease management options in two different contexts. Concerns identified in Quebec included public health effectiveness of interventions in reducing disease impacts, social acceptability of interventions, costs of interventions, operational effectiveness

including delay, complexity, sustainability and other policy impacts, as well as animal and environmental impacts of proposed interventions. Adaptation of the WNV model to malaria in Burkina Faso revealed many shared concerns; however additional concerns were raised that are specific to the Burkina Faso context including the capacity to differentially diagnose malaria from other diseases with similar symptoms (e.g. dengue), the effect of interventions on public awareness of malaria and costs born by families as well as non-governmental organizations. Early symptoms of dengue and malaria are similar (Ridde et al., 2014) and while rapid diagnostic testing for malaria is recommended by the WHO prior to treatment (WHO, 2015c), this course of action is not always followed (Bastiaens et al., 2014; Ezeoke et al., 2012) or even when testing occurs, test results are not always adhered to and may result in incorrect treatment with anti-malarial medication (Juma and Zurovac, 2011), a practice that can contribute to increasing drug resistance and other unintended consequences (Amexo et al., 2004). These examples illustrate the value and importance of including considerations that extend beyond cost-effectiveness of interventions alone in order to craft strategies that are acceptable and appropriate for the region. Our analyses enabled a systematic evaluation of and identification of complementarity interventions for both diseases thus contributing to the development of an approach for the construction of more robust public health responses.

Contributions to adaptation research and global health

Given the significant global burden of vector-borne diseases, long known links between climate and VBDs (Altizer et al., 2013), and unavoidable commitment to climate change as a result of existing greenhouse gases in the atmosphere (IPCC, 2007a), adaptation to climate change impacts, including VBD impacts, has become essential. However, adaptation planning has been primarily limited to the planning stage and an 'adaptation deficit' has been observed in terms of the limited actions taken to date (Adger and Barnett, 2009; Berrang-Ford

et al., 2011; Noble et al., 2014). This inaction has been attributed to numerous barriers that surround adaptation (Biesbroek et al., 2013; Eisenack et al., 2014). As a result, it is essential to develop strategies to overcome existing barriers and facilitate adaptation action. In this research, we have proposed and described a three-phased approach to managing vector-borne disease risk under climate change that can help to address some of the existing barriers to adaptation action.

Barriers to adaptation identified in the literature vary by context but have been loosely categorized as an inability of natural systems to adapt, technical, financial, institutional, social, informational, cultural and cognitive barriers (Adger et al., 2007). Biesbroek and colleagues further emphasized that barriers are mediated by the interpretation of the actors involved (Biesbroek et al., 2013) and thus reinforce the need to include affected stakeholders in the process in order to better understand the dimensions of the problem. Furthermore, Adger stressed that fair adaptation processes must include an opportunity for stakeholders to be involved in the process itself and weigh in on the strategies put forth (Adger, 2013). Adaptation planning for vector-borne disease in particular has been hampered by the complexity inherent in the existence of and interacting nature of multiple drivers of disease risk, and further complicated by climate signal attribution challenges, lack of model consensus, increasing insecticide and drug resistance, financial instability of funding bodies, and multiple layers of uncertainty with respect to time scales, spatial scales, and other ecological and epidemiological factors of disease risk (Campbell-Lendrum, D., 2015; Parham et al., 2015a).

With this awareness in mind, our research offers a generalizable, evidence-informed approach to planning climate change adaptation. The examination of three key phases: *impact assessment through disease prioritization, vulnerability assessment through population readiness and*

adaptation assessment through vector-borne disease management, contributes to informing necessary and important preliminary steps for adaptation action to manage vector-borne disease risk. Our research allowed insight into the concerns expressed by stakeholders relevant to these decision phases, an appreciation of what concerns are shared both among stakeholders in a specific region and across contrasting contexts, local contextualization of the problem and preliminary assessment of gaps in our knowledge and understanding on these issues.

Addressing informational barriers and uncertainty

The systematic documentation of options over identified concerns contributes to reducing informational barriers and challenges by enabling a synthesis of multiple forms of knowledge, including both available quantitative and qualitative scientific knowledge, as well as stakeholder knowledge and experience on the issues. The process can also accommodate varying levels of certainty and varying contexts of evolving disease risk (climate change induced or other). In so doing, it enables the evaluation of options even where existing information is patchy as knowledge gaps can potentially be filled by expert opinion or local stakeholder knowledge. Documenting existing knowledge gaps also contributes to indicating directions where further research is needed.

Much uncertainty surrounds the time-scale and spatial-scale of anticipated climate change impacts on vector-borne disease which can impede adaptation planning and action. Here descriptive scenarios of anticipated future impacts were used to assess adaptation options of interest for managing WNV risk in Quebec. Descriptive transmission scenarios of low-, medium-, and high-risk transmission were used to examine the potential effectiveness and complementarity of management measures now and under hypothetical, climatically plausible, intensified WNV transmission. The scenarios themselves

were not meant to be predictions, but rather used to examine whether stakeholder values might shift under these different scenarios and what impact these changes in values might have on preferred interventions. This highlighted those management measures which remained acceptable and of interest under the different settings (i.e. larvicides at a regional-level). Conversely, those measures which do not become more attractive even under scenarios of intensified transmission were also made evident (i.e. adulticides and dissemination of sterile male mosquitoes at a regional-level). In our case, this evaluation suggested that given values expressed by participating stakeholders, the strategies currently in use to manage WNV in Quebec (e.g. personal preventive behaviours and larvicides) remain equally of interest in hypothetical future scenarios of intensified WNV transmission. In Burkina Faso, only current transmission scenarios for malaria were examined as stakeholders felt already overwhelmed by the existing malaria burden in the country. In addition to the use of descriptive scenarios, sensitivity analyses available in the MCDA approach enable us to test various assumptions and assess their importance and effect on outcomes of interest in the model. This can help overcome some of the barriers to action by nuancing the levels of uncertainty and by identifying variables that need to be better understood before action can be taken.

Reducing institutional and cognitive barriers

The use of a multi-stakeholder approach in this process with local stakeholders from various institutional and disciplinary backgrounds can help reduce some of the institutional and cognitive barriers surrounding adaptation action. The facilitation of exchanges between key stakeholders under a shared objective offers an opportunity both to hear from groups not normally involved in these types of processes as well as for these groups to hear each other's points of view, fostering shared learning and knowledge translation opportunities between these groups. While disease prioritization exercises have previously been

conducted with non-disease experts (Brookes et al., 2014a; Ng and Sargeant, 2012a), this study is the first to explore joint deliberation between experts and non-experts in the areas of VBD prevention and prioritization. While potentially challenging and subject to discussion dynamics where certain voices may take up disproportional space compared with others, this forum offers an opportunity to broaden the scope of the problem beyond disease expert perspectives alone. A broader stakeholder inclusion in the process provides opportunities for stakeholder buy-in into the process as well as a chance to hear and consider different stakeholders' knowledge and experiences in the process. For instance, the insight from a sociologist into why treatment is not always sought even when experiencing symptoms suspected to be malaria, underlined the importance of local perspectives in adapting scientific evidence into practice. When rural villagers are sick with what they suspect to be malaria, they may not seek standard medical treatment as doing so would require missing work since treatment centers may not be conveniently located. As a result, traditional healers may be consulted instead.

The opportunity to hear from and deliberate between stakeholders from various institutional and disciplinary backgrounds is an added opportunity for shared learning, and knowledge translation between these groups. The deliberative approach requires an openness to the process of discussion and deliberation and willingness to hear and consider the views of others. This allows an opportunity to recognize divergence of opinions among stakeholders and also provides an opportunity for shared learning to occur. This requires patience on the part of participating stakeholders, and can be a time-consuming process. However, the potential utility of these results can extend beyond the initial problem statement allowing for a deeper contextualization of the issues of concern based on the experiences and knowledge shared by participating stakeholders. Additionally, this exchange between stakeholders fosters

opportunities for deeper appreciation of diverse perspectives and increases the potential for buy-in and alignment between stakeholders towards a concerted strategy for future adaptive action.

Cultural contextualization

With regards to increased contextualization opportunities, while constructing the model to assess management strategies for malaria in Burkina Faso, the WHO recommended practices were the first interventions to be included in the model. However, numerous alternative interventions were proposed by stakeholders including the use of traditional plants to repel mosquitoes (in various forms such as creams or teas for example), traditional plants for treatment of malaria and as rapid diagnostic tests. Valuing traditional healers and environmental spaces was also proposed in order to contribute to the protection of traditional plants and environments for preventive and medicinal purposes. Traditional plants and medicine have frequently been used in many areas of Burkina Faso alongside western medicine (Okrah et al., 2002) and a number of studies have begun to examine their effectiveness (Nadembega et al., 2011; Pohlit et al., 2011). Certain plants have been shown to demonstrate mosquito-repellent effects (Bassole et al., 2003; Georges et al., 2008) and antiplasmodial effects (Jansen et al., 2010; Sanon et al., 2003b). Botanical diversity is currently threatened as a result of increasing human population, development and overexploitation that has been ongoing in the West African region due to desertification and resulting in large migration of human populations into more southern regions (Ouedraogo et al., 2010; Paré et al., 2008). A valuing of local healers and plants with emphasized valuing and protection of plants used in traditional medicine could contribute to environmental sustainability in the region. While literature evidence may be inconclusive and currently insufficient as to the relative effectiveness of these alternative interventions, the strict reliance on WHO recommended interventions

alone by external funders may be contributing to the erosion of locally valued knowledge and practices. Further research on locally sourced and grown products as supplemental and complementary courses of action to WHO recommended core interventions could potentially offer more sustainable and affordable local options aligned with existing local practices and thus more apt to be adopted and maintained by local communities. These and other interventions were topics that local researchers expressed interest in investigating further, however, due to the financial challenges of the country, researchers currently have very little autonomy in selecting their own research topics. Furthermore, in the cases where research already exists, stakeholders expressed frustration at poor promotion and translation of local research results into practice (Kouyaté et al., 2007). Although contextually different, the erosion of traditional knowledge and practices of Inuit communities in the Arctic has been linked to increased vulnerability and reduced adaptive capacity of these communities to climate change (Ford et al., 2008). Care should be taken in the imposition of external values on foreign communities especially if these threaten to displace existing ways and knowledge.

Contributions of a comparative approach

The comparative aspect of our study enabled us to begin to better understand and distinguish generalizable concerns in disease prioritization and management assessment versus locally nuanced concerns. One the one hand, the WNV management options under consideration in Quebec represent a range of concerns for a disease with currently low levels of transmission while on the other hand, the malaria management options under consideration in Burkina Faso represent a range of concerns for a disease under high-transmission intensity. Although additional operational and socio-economic differences prevail between these two settings, this contrast offers some insight for both regions into the range of options that may be considered in different settings for

different diseases and can potentially motivate further research into new options to consider. From a practical modelling perspective, these experiences help to refine and improve adaptation models to new diseases and contexts.

Our study in two very different epidemiological and socio-economic contexts offers insight into understanding which concerns are universal versus those that are more context specific. The disease prioritization and disease management phases in particular were explicitly tested in different settings and demonstrate how an approach based on similar concerns can be re-appropriated and customized to reflect local realities informed by the latest scientific evidence as well as stakeholder experiences and concerns applicable to a specific context. The results highlighted well-known differences in public health capacity between the two countries including differences in operating realities as a result of financial constraints with their inevitable implications on decision autonomy. At a global scale where significant financial aid is distributed to assist with health concerns in low- and middle-income countries, there is a need to regularly evaluate whether concerns are universal or whether each country and region requires its own priority assessment that will inevitably guide future resource allocation for a region. Additionally, the impact of that aid on local decision autonomy is a significant concern that requires further attention and research. MCDA approaches to disease management have been explored previously (Aenishaenslin et al., 2013, 2015), and this work further contributes to supporting and demonstrating the ability of this type of approach to contribute to evidence-informed planning of complementary and robust strategies to manage vector-borne disease threats.

While our use of a multiple-correspondence analysis approach to assess vulnerability was not tested in a separate country context, this approach offers insight into understanding the heterogeneity of a population which is of interest for planning effective adaptation strategies. Additionally, of interest in the

context of climate change adaptation is what this portrait of a population`s knowledge and practices with respect to mosquitoes and mosquito-borne disease (WNV in this case) might suggest about how the population will react to future disease threats. Füssel and Klein (2004) suggested prerequisites to effective adaptation. These included awareness of the problem, availability of effective adaptation measures, information about these measures, availability of resources for implementing the measures, cultural acceptability, and incentives for implementing the measures (Füssel, 2007b). WNV has become endemic in southern Quebec and has been circulating in the province for 15 years. Our study reinforces the observed trend that knowledge levels of WNV and personal protective practices have increased in the province, suggesting that the population has been receptive to public health messaging on mosquito-borne disease over the described timespan. These findings demonstrate that the prerequisites suggested by Füssel and Klein, awareness, information on measures and acceptability in particular, are in place for effective adaptation to WNV from a population response perspective.

Not a panacea, but an additional tool in the adaptation toolbox

The use of a structured approach such as deliberative MCDA offers users "a guided path" by which to proceed, which can help navigate the potentially vast amount of information that feeds into this process. It does not solve the adaptation deficit entirely, but contributes to a practical organization of what we know in order to facilitate adaptation action. A summary of contributions from this approach to adaptation research are shown in Table XXXIII. Available knowledge and conversely, existing knowledge gaps are recorded in the process providing systematic documentation on how evaluations were performed and pointing to additional research needs. Additionally, stakeholder-informed knowledge and experience can help identify additional barriers that require addressing on the road to adaptation. While the financial challenges of Burkina

Faso are not new knowledge, the nuancing of financial aid and its effects on research priorities and efficient local availability of testing and treatment methods, and further highlights barriers to local development of adaptation options such as environmental and traditional plant options to reduce mosquito bites and malaria burden.

Table XXXIII. Contributions to adaptation research

MCDA steps	Contributions
Problem structuring	
Identifying options	• Assessment of the breadth of available evidence related to the problem • Contextualization of existing evidence with local experience and knowledge • Opportunity to identify gaps in knowledge and needs for future research • Identification of potential barriers • Identification of opportunities for new collaborations
Defining and weighting criteria	• Mapping and weighting of concerns • Opportunity to solicit different perspectives related to the problem • Opportunity to broaden the language and vocabulary related to the problem • Opportunity to expand understanding of the problem • Opportunity to identify shared concerns and divergences • Opportunity to align vision and planned actions around next steps
Decision analysis	
Prioritization	• Relative ranking of options in relation to their strengths and weaknesses
Sensitivity analysis	• Identification of pivotal concerns and weight thresholds that affect decision making
Intangible outputs	• Opportunity to consider different perspectives • Opportunity for shared understanding and knowledge translation around decision problem • Opportunity for increased ownership and appropriation of the problem by participating stakeholders • Space to deliberate different views and opportunity for high quality conflict • Insight into complexity and nuance of decision problem • Opportunity for improved understanding of stakes and trade-offs • Opportunity to align vision and increase stakeholder buy-in around planned actions and next steps

While deliberative MCDA approaches are not simple, neither is the management of vector-borne disease threats under climate change. The concerns (i.e. criteria) identified in the disease prioritization and disease management examples in this research can serve as a starting list for future exercises. Space in time between meetings is important in this process in order to allow for

reflection, and in order to offer participants the opportunity to shift their perspective on the problem by taking other viewpoints into account. The deliberative MCDA approach facilitates a structured approach to a messy problem while enabling contextualization of the inherent complexity through available local evidence and stakeholder-informed experience. The deliberative MCDA approach should be thought of as an *evolving* process, to be repeated and refined with time and experience. Knowledge on a problem and perspectives of stakeholders' change with time, hence the importance of revisiting and re-assessing MCDA exercises on a regular basis in order to maintain an updated understanding of evolving problems. Furthermore, ongoing surveillance remains essential in order to monitor the progression of diseases and continue to inform public health action. This research thus serves as a snapshot in time of current knowledge and values of Quebec and Burkina Faso with respect to vector-borne disease adaptation to climate change.

Study Challenges and limitations

Many of the limitations to this research project were presented in their respective chapters. Nevertheless, some of these are revisited in the section that follows and discussed in the scope of the overall research project.

Overall study design and implications for causality

The study design for this research project was cross-sectional, and examined the current concerns of participating stakeholders with respect to VBD prioritization and VBD management in Quebec and Burkina Faso, as well as current knowledge and preparedness of residents of southern Quebec to mosquitoes and WNV. As a result of this design, causal association cannot be established and our results may not be an accurate predictor of future contexts or behaviour. Nevertheless, this snapshot can serve as a baseline for comparisons

with future research and contributes important preliminary knowledge for informing future actions.

The order in which the different country-level processes were conducted where models were developed in Quebec and then adapted in Burkina Faso likely had an influence on the list of criteria retained in the models. Had the reverse order occurred, with the initial model developed in Burkina Faso and then adapted in Quebec, a different final set of criteria might have emerged. Given the ease of consultation of the scientific literature, there is significant cross-learning expected between studies and regions. Nevertheless, the elements retained in the Burkina Faso model represent a set of validated concerns for the group of consulted stakeholders and in the spirit of constructing the most comprehensive set of criteria in a model, these results contribute examples for future research.

MCDA model validity and potential bias

Another important limitation pertains to the pilot project nature of the assessments of the MCDA models which as a result cannot be interpreted as formal assessments of the countries in which they were performed. As such, inference is limited at this stage. Further formal assessments with different stakeholders are warranted to examine whether the same concerns hold, what additional concerns may be of interest to include and their overall effect on disease and management strategy prioritization and planning. While the group of participating stakeholders was diverse, they were for the most part selected by convenience as a result of existing contacts within their respective country settings and as such, subject to selection bias. Stakeholders contacted for participation in the MCDA processes were selected in an attempt to include as broad a set of actors as possible with relevant knowledge (e.g. infectious disease experts, entomologists, environmental experts, sociologists, veterinarians), existing experience (e.g. Water, Sanitation and Hygiene project members, field

doctors) or potential to be impacted (e.g. citizen representatives) by VBDs. The models constructed are thus representative of the values held by the set of stakeholders involved who acted as spokespersons for their relevant area of expertise or experience in the context where the models were constructed and thus could vary if constructed with a different set of stakeholders. The MCDA approach is based on a socio-constructivist paradigm and the validity of results are not based on strict reproducibility of results, but rather the representativeness of society or relevant group of experts. The validity is also intimately tied to the coherence and transparency of results that are modeling a complex system. Furthermore, in conjunction with the consent forms signed by stakeholders guaranteeing anonymity, we did not provide specific details on the identity of participating stakeholders in our study. This decision was challenged during publication due to concerns that proper differences in stakeholder opinions could not be assessed without knowing specifics on who stakeholders were. While privacy laws vary by country, in the context of Quebec privacy laws we felt this to be a crucial ethical decision to not further reveal stakeholder identity. This approach is not without precedent as it is coherent with the Chatham House rule (https://www.chathamhouse.org/about/chatham-house-rule) which is frequently used in deliberative processes, where the content of discussions can be shared by participants but the identity and affiliation of participating stakeholders cannot be revealed.

With regards to stakeholder perspectives, although different stakeholders may have different preferences or biases with respect to the concerns (i.e. criteria) addressed in the models, the evaluations of diseases and management options were performed separately from stakeholder weighting of criteria. Evaluations were based primarily on the scientific literature and thus not subject to stakeholder information bias at this stage. The choice of criteria was potentially subject to stakeholder bias, but reduced by having a common set of

criteria that required approval by participating stakeholders thus increasing transparency and reducing the effect of any single stakeholder's views fully directing the model.

Potentially confounding factors such as drug or insecticide resistance, and socio-economic effects were included in the MCDA models to the extent that these were acknowledged by stakeholders as relevant to the decision problem and to account for the potential effect of various disease management options on these factors. However, evaluations of management options on these factors was limited by available data in the literature. Furthermore, interactions between management options were not explored at this stage but should be addressed in future work.

Population survey

The inclusion of a survey to assess population vulnerability is subject to a number of important limitations including the validity of the survey instrument itself, the selection of respondents, and potential response bias of participants. First, with respect to the validity of the survey instrument, our questionnaire was constructed from existing studies on WNV and mosquito-borne disease and concepts coherent with the Health Belief Model. However, given the augmentation of the questionnaire to include additional concepts, such as sense of responsibility, not strictly contained in the Health Belief Model, the repeatability of measured constructs will need to be further studied. Additionally, the survey was administered in both French and English, and hence translational coherence of results requires further study. Our initial pre-survey sample yielded comparable responses that were not significantly different between English and French respondents. These responses were also coherent with the questions asked. However, given the unequal number of respondents in both languages (628 respondents in French and 176 respondents in English) and thus diminished

capacity to detect true differences, we cannot rule out the possibility that certain response trends were not a result of the questionnaire's translation. With respect to participant selection, respondents were selected by web panel based on their residence within seven administrative regions of southern Quebec. This likely introduced a certain degree of selection bias given that only those with internet access had the potential to be included in the panel. A 2012 survey found that while access varied by regions, overall 90% of Quebec households had access to internet and none of the least connected regions were included in our survey sample (Cefrio, 2016; Institut de la statistique du Québec, 2013). Secondly, in terms of the representativeness of the survey sample, comparison with income statistics available for the province of Quebec suggests that the respondents from the lowest income group (<40,000$) were likely under-represented in our sample (Statistics Canada, 2016).

Additionally, results found cannot necessarily be inferred to the larger Quebec population as only residents from seven administrative regions with known WNV activity were surveyed. The survey was administered in the spring of 2016 when mosquito activity was far from its peak. Respondents were thus subject to recall bias as they would have had to rely on their memories from summer 2015 behaviours while responding to the survey. This may have increased the desirability bias of respondents to give answers they thought were correct to the survey questions. Both would have contributed to a misclassification bias of responses and may have thus resulted in an under- or overreporting of protective behaviours. Adoption rates were nevertheless comparable to other studies conducted in Canada and the United States and thus we do not believe this impact was significant. Additionally, while we would like to infer results from our study to further characterize the adaptation readiness of the Quebec population to future mosquito-borne disease threats, our results may not be directly generalizable to other mosquito-borne diseases particularly if the

rate of contact between humans and the transmitting mosquito species are very different than WNV or the preferred habitat and hence transmission zones of other diseases are very different than WNV. Additionally, individual's perception of new diseases may differ and thus modify their adoption of protective behaviours.

Next steps and broader applications of the research

The world is currently experiencing the early effects of climate change, from warming of global air and ocean temperatures, rising of sea level, and melting of snow and ice with consequential increases in heat waves, droughts, floods and extreme weather events (IPCC, 2007a). These are among early visible impacts of climate change with further effects anticipated given accumulated GHG in the atmosphere (IPCC, 2007a). Some adaptation action has begun, but there is still a long road ahead in reducing climate change and its effects on human health and the planet. This thesis has contributed an evidence-informed approach to climate change adaptation to vector-borne disease risk by identifying concerns of importance to consider in prioritizing diseases under climate change, assessing population knowledge and preparedness to WNV in Quebec and assessing management strategies for WNV in Quebec and malaria in Burkina Faso. This contribution is but a preliminary step in vector-borne disease adaptation planning and additional research is warranted to reduce the anticipated impacts of vector-borne disease under climate change and further our collective adaptive capacity to these changes.

Additional primary research in traditional public health domains of action

Ongoing effort in vector-borne disease research, surveillance, prevention and treatment is needed to help reduce vector-borne disease burdens. Many knowledge gaps exist and further research on the ecological and epidemiological

aspects as well as social determinants of vector-borne disease interaction with climate change are needed in order to continue to inform adaptation action. While some of the management options examined in this thesis included broader-scale vector or environmental control options (options that are generally managed by regional public health authorities), many of the first-line prevention recommendations require individual behavioural awareness and adoption of practices to protect oneself directly from the risk of infection (e.g. use of insecticide treated nets or DEET containing repellents). In parallel to research, surveillance of both vectors and disease are needed to help target and plan specific adaptation action.

Complementary to disease research and surveillance efforts, further advances in prevention and treatment tools such as vaccines are needed in order to fortify adaptation strategies. Much public health success and progress over the last century has been achieved as a result of safe, effective and affordable vaccines (Schlipkoter, and Flahault, 2010; Stern and Markel, 2005) but also improved living standards as a result of regulations for sanitation, food and water (Schlipkoter, and Flahault, 2010). Despite our many achievements, communicable diseases continue to pose an important threat to human health and new and emerging diseases have appeared amidst ongoing global changes such as climate change. While vaccines alone will likely not be the panacea for all new and re-emerging diseases, considerable infectious disease burden can be reduced with the ongoing development of safe and effective vaccines. Further research into effective vaccines for malaria and other vector-borne diseases such as dengue, which pose a considerable burden to low- and middle-income countries, is warranted to add to the arsenal of tools available to help reduce the burden of infectious diseases in these countries. Additionally, further research into safe and effective treatments for these diseases remains important especially where drug and insecticide resistance have become an issue (e.g. malaria (Hastings, 2003)). In

parallel with these biomedical approaches to disease control, further vector-control and reservoir host targeted control approaches require ongoing research effort as well. Ongoing efforts to reduce other drivers of disease such as poverty, environmental degradation and insufficient health capacity must also continue. As they are developed, all of these approaches will need to be evaluated within comprehensive frameworks such as an evidence-informed MCDA, open to understanding the underlying determinants of infection in the contexts where they occur in order to mount effective management and adaptation strategies to disease.

Characterizing population heterogeneity to tailor adaptation

With respect to the vulnerability assessment aspect of our work, at a local level, further examination as to whether the different subgroups found within our study extend to the broader Quebec population is warranted. Additionally, while time and resources did not permit an examination of the knowledge and current practices of Burkina Faso residents to mosquito-borne disease, it would be interesting to examine whether similar subgroups exist in Burkina Faso and in other settings and examine how these different subgroups may relate to vector-borne disease risk. It would also be interesting to examine how other populations perceive sense of responsibility for protecting their health in relation to their sense that it is public health authority`s responsibility to protect them and assess whether the two are mutually exclusive or not. In particular, what insight might this information offer us in planning future mosquito-and vector-borne disease management strategies and climate change adaptation strategies. The subgroups found within the Quebec population present an opportunity to further investigate the creation of tailored communication messages and examine how different subgroups respond to different messages. Similar work has begun in the broader communication of climate change impacts on public health messages (Maibach et al., 2010). Further research in Quebec and other regions would be

interesting to examine to what degree subgroups may be geographically distinct. In our study, our results suggested that the "unconcerned citizen" appeared more closely associated with residents of the Quebec City area, an area that has seen very little WNV activity to date, but further investigation is warranted to examine how broadly different subgroups may extend to the general population and how they are distributed in space. This will help contribute to improved public health messaging in risk areas.

Broader vector-borne disease and transmission contexts

While our research has demonstrated the potential to construct contextualizable, evidence-informed MCDA models to assess and plan management strategies for a number of vector-borne diseases (WNV and malaria in this current research project and Lyme disease previously), further assessments with other diseases in additional contexts should be explored to continue to refine and improve the models. We showed how models can be adapted to very different contexts and adjusted to take into account local concerns in the process; however, further research is needed to determine the extents and limits of this approach and in particular clarify when and where this approach may not work. For example, how appropriate is this approach in very vulnerable contexts such as indigenous or aboriginal health related contexts? The ability of the MCDA approach to incorporate multiple values, beyond cost-effectiveness alone offers additional flexibility to adapt these models to the local cultural contexts in which they are applied. In fact, MCDA approaches have been used in environmental management processes involving First Nations people in Canada (Failing et al., 2007). However, a model is only as good as the data used in its construction and translating local concerns into measurable criteria is not a trivial task. Adaptation of these models into new contexts will need to be done with patience and in collaboration with local stakeholder that are able to articulate their concerns with respect to the disease setting of interest. In

addition to this, a more formal evaluation of these types of adaptation planning exercises in collaboration with local governments is warranted to examine what practical constraints may exist in streamlining these processes into public health policy and decision making. As knowledge progresses on the impacts of climate change globally, these insights can serve as further inputs in the model to help extend our understanding of what constraints on adaptation may need to be considered over time.

From a policy perspective, the use of deliberative MCDA offers an opportunity for transparent agenda setting between decision makers and broader stakeholder groups that include the general public by enabling explicit evaluation of decision alternatives over the shared concerns of experts and the public. This approach offers an opportunity for shared learning and knowledge transfer between groups and increased buy-in and acceptance of resulting decisions by all participating stakeholders.

CONCLUSIONS

This thesis has furthered our understanding of decision elements of importance to consider in adapting to vector-borne disease risk under climate change, in particular, by contributing to assessing diseases of concern under climate change, assessing vulnerable and at risk groups to these diseases and assessing disease management strategies. We found that:

- Shared disease prioritization concerns exist in different contexts and countries; however, different priorities may emerge as a result of contextualized assessments of data parameters and stakeholder valuation of concerns.
- Different subgroups exist within a population with different motivations for adopting mosquito protective behaviour and resultantly have different corresponding levels of vulnerability to mosquito-borne disease risk. These must be considered in the construction of more tailored public health communication messages and future adaptation strategies.
- Disease management strategies can be explored under varying transmission scenarios and country contexts in order to seek complimentary, acceptable, and tailored adaptation strategies to more robustly manage vector-borne disease risk under climate change over time.
- Deliberative, evidence-informed approaches, such as MCDA, are a generalizable and contextualizable approach that can be used to inform climate change adaptation planning. This approach enables a cross pollination of knowledge and perspectives thus contributing to a

richer understanding of complex problems. This demonstrates an example of an evidence-informed approach for vector-borne disease management which can also be applied in broader global and public health contexts.

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APPENDIX 1: SUPPORTING INFORMATION FOR CHAPTER 2

Criteria for the Prioritization of Public Health Interventions for Climate-Sensitive vector-borne Diseases in Quebec

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List of Supplementary Materials:

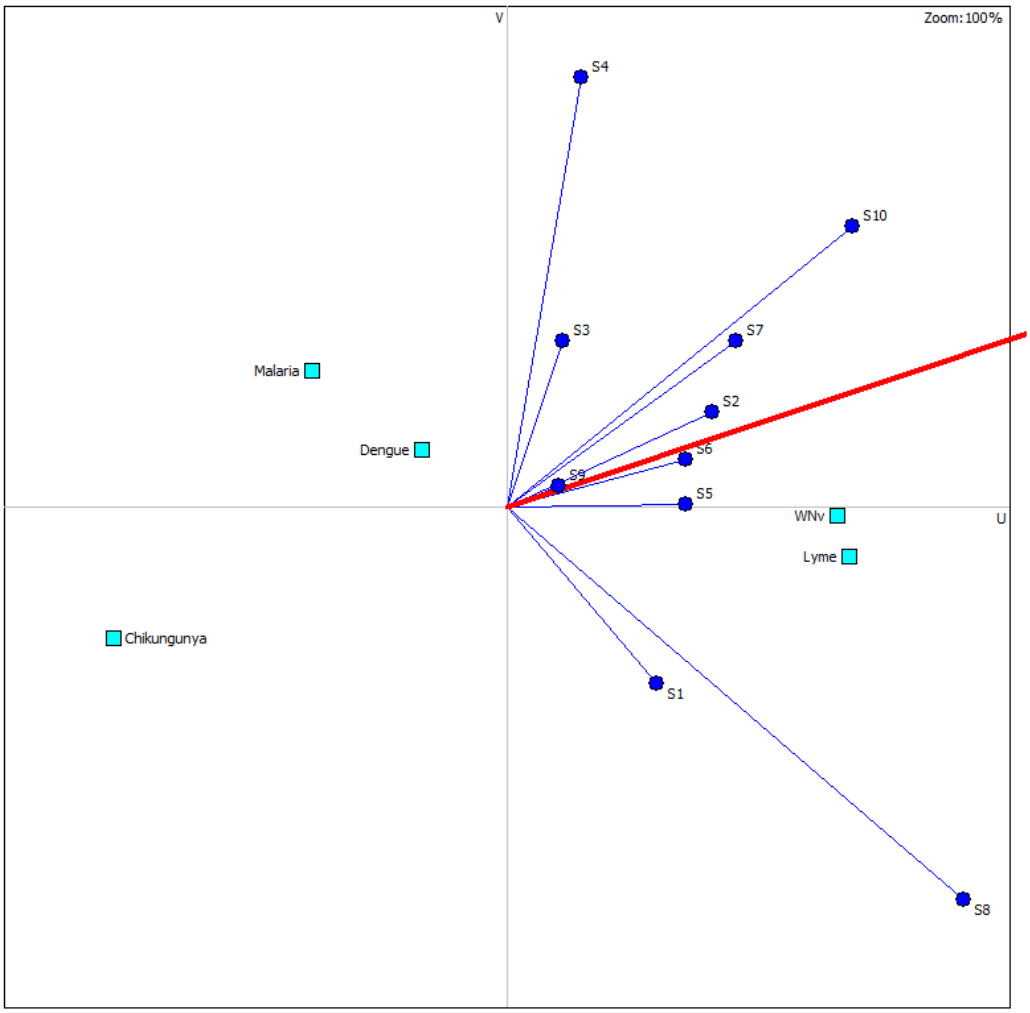

Figure 13. GAIA decision map for the "Surveillance" intervention domain.

The bold red line represents the group decision or consensus ranking with the solid circle at the end pointing in the direction of the group ranking. Square markers represent the ranking of the different diseases in *k*-dimensional space projected onto a 2-dimensional plane. Diseases closest and in the same direction as the group axis are ranked ahead of diseases further away from the decision axis. Stakeholders 1 through 10 are represented by the blue circular markers labelled S1-S10. Stakeholders pointing in the same direction as the group decision axis are most aligned with the resulting ranking. Stakeholders far away in space from each other and from the group decision axis have more different weights and hence perspectives.

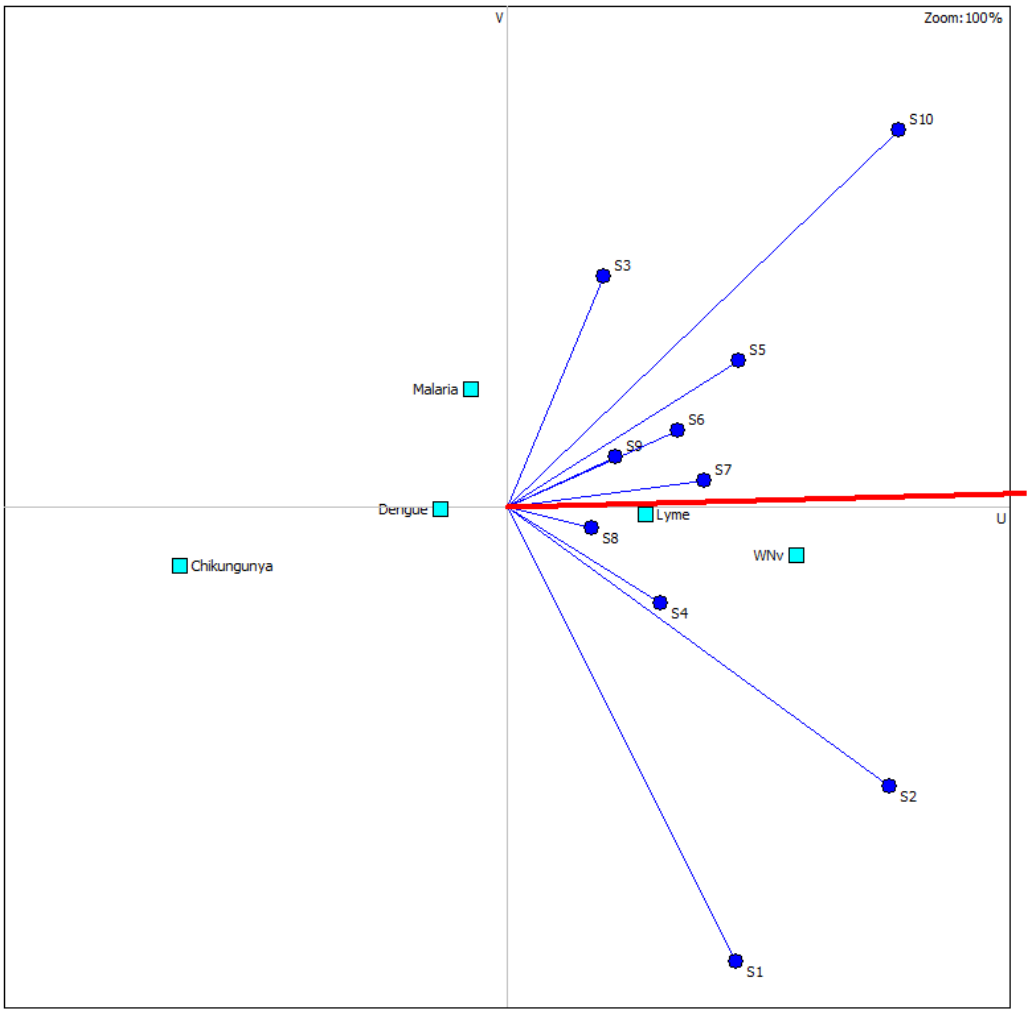

Figure 14. GAIA decision map for the "Prevention & Control" intervention domain.

The bold red line represents the group decision or consensus ranking with the solid circle at the end pointing in the direction of the group ranking. Square markers represent the ranking of the different diseases in *k*-dimensional space projected onto a 2-dimensional plane. Diseases closest and in the same direction as the group axis are ranked ahead of diseases further away from the decision axis. Stakeholders 1 through 10 are represented by the blue circular markers labelled S1-S10. Stakeholders pointing in the same direction as the group decision axis are most aligned with the resulting ranking. Stakeholders far away in space from each other and from the group decision axis have more different weights and hence perspectives.

Table XXXIV. Criteria Trace Summary

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
PH	21	Incidence or prevalence, occurrence in humans, burden of ill health, illness rate, %	1	1	-	1	1	-	1	1	1	-	1	1	1	-	1	1	1	2	2	1	1	1	-	1	1	PHC-01
PH	19	Morbidity, severity of symptoms, consequences for humans, work and school absenteeism, impact on quality of life, Clinical course	1	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	-	PHC-02
PH	4	Duration of illness, chronicity of illness or sequelae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	PHC-02
PH	14	Deaths, mortality, death-case ratio, case fatality rate (humans), fatality	2	-	-	-	-	-	-	1	-	-	1	-	-	1	1	1	1	2	1	1	1	1	-	1	1	PHC-02
SP	16.5	Public concern & perception of risk, social sensitivity, public attention	1	1	-	1	1	-	1	1	1	-	0.5	-	-	-	0.5	2	1	2	2	-	0.5	-	1	-	-	SIC-01

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
SP	1	Public awareness	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	SIC-02
LO	2	Potential to drive public health policy, political impact of disease in humans	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	0	1	-	-	-	-	-	-	
RE	9.5	Communicability, potential to spread to general population, human-to-human spread	1	-	-	1	-	-	-	-	1	1	-	-	0.5	1	-	-	-	0	2	1	-	-	-	-	1	REC-02
RE	8	Epidemic or potential for outbreaks	1	-	-	-	-	-	-	1	1	-	1	-	1	-	1	-	-	1	-	-	1	-	-	-	-	REC-02
RE	8.5	Appearing to change over time, trend	-	-	-	1	-	-	-	-	1	-	1	-	-	-	0.5	-	1	0	1	1	1	1	-	-	-	REC-02
RE	10.5	Emerging potential, prob. of introduction	-	1	1	-	1	-	1	1	-	1	1	-	-	1	0.5	-	-	0	-	-	1	-	-	-	1	REC-01
RE	7	Mode of transmission, speed of spread	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	3	3	-	-	-	-	-	-	
AE	11	Occurrence in animals	-	-	-	-	-	-	-	-	-	4	-	1	1	1	-	-	-	7	3	1	-	2	-	-	-	AEC-01
AE	4.5	Consequences of spread in animals, severity	-	-	-	-	-	-	-	-	-	4	-	0.5	-	-	-	-	-	0	1	1	-	1	-	-	-	AEC-02

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
AE	3	Animal Case fatality rate (mortality)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1	-	1	-	1	-	AEC-02
EC	16.5	Socioeconomic impact, market loss, econ. damage	1	1	-	1	1	-	1	1	1	-	-	0.5	1	1	-	1	-	6	3	2	-	1	-	2	-	
EC	2	cost of illness	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2	-	-	-	-	-	-	-	
EC	1	Govt compensation to industry (to compensate for losses)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	1	-	
EC	1	Econ Impact on animal industry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	
LO	15.5	Preventability, health gain opportunity	1	1	-	1	1	-	1	1	1	-	1	-	2	-	1	-	1	3	0.5	-	1	1	-	-	1	
LO	9.5	Treatability, treatment possibilities and needs (in humans) (including AMR)	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	1	2	0.5	-	1	1	-	-	1	
LO	6	Diagnostic ability (and quality) in humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	3	-	-	1	-	-	1	

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
LO	7.5	International considerations, notification regulations in national public health, duties, obligations	1	-	-	1	-	-	-	1	1	-	0.5	-	2	-	0.5	-	-	0	-	-	0.5	-	-	-	-	
LO	4	Scientific Knowledge of pathogenic agent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	-	1	-	-	-	
LO	4	Immediate public health response necessary, timeliness	1	-	-	-	-	-	1	-	1	-	-	-	-	-	1	-	-	0	-	-	-	-	-	-	-	
LO	2	Other sector interest (incl. Agriculture Canada)	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	
RE	4	Evidence for pathogenesis	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	0	1	-	1	1	-	-	-	REC-02
RE	2	Current geographical distribution in region of interest and risk of expansion	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	0	1	-	-	1	-	-	-	REC-02
PH	5.5	Evidence for risk factors, high risk groups	-	-	-	-	-	-	-	-	-	-	1	-	0.5	-	1	-	-	0	1	1	1	-	-	-	-	

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
PH	2	Health care utilisation, proportion of events requiring public health action	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	PHC-02
LO	2	Elimination potential (in humans)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	0	1	-	-	-	-	-	-	
LO	2	Validity of epidemiological information	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	0	-	-	1	-	-	-	-	
LO	2	Existence of surveillance or studies in animals or vectors	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	0	1	-	-	-	-	-	-	
RE	3	Transmission potential between animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-	-	-	
RE	4	Transmission potential from Animal-human, zoonotic potential	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	0	1	1	-	1	-	-	-	REC-02
LO	2	Treatment possibilities in animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	
AE	2	High-risk groups in animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	
AE	2	impact on animal welfare and	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	AEC-02

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		biodiversity																										
RE	2	Transmission potential from humans to animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	REC-02
RE	2	Animal Trend last 5 years	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	REC-02
AE	1	Specific animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	
AE	1	Animal attack rate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	AEC-02
AE	1	Classification of zoonoses	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
AE	1	Lower human consumption of animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
AE	1	Zoonotic / common agent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
AE	1	Likely incidence in domestic animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	AEC-01
AE	1	Pathogenicity in domestic animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	
AE	1	Potential environmental impact	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	
AE	1	Potential social impact	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	
EC	1	Impact on int'l trade	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	
LO	1	Simplicity,	-	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	0	-	-	-	-	-	-	-	

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		sustainability																									
LO	1	Existing control measures, or surveillance programs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-
LO	1	Previous classification status	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-
LO	1	Surveillance feasibility	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	0	-	-	-	-	-	-	-
LO	1	Diagnostic ability (and quality) in animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
LO	1	Control measures animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
LO	1	Control measures humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
LO	1	Disease in human beyond control measures	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
LO	1	Human cause versus natural cause	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
LO	1	Potential to eradicate disease in animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
LO	1	Risk of bioterrorism	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
LO	1	Risk to food and	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		water																									
LO	1	Surveillance in humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	
LO	1	Vaccine/antiviral manufacturing time	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	
LO	1	Visual cues to avoid disease in humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	
LO	1	Counter measures	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	
LO	1	Evidence assessment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	
LO	1	Resources	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	
LO	1	reservoir or vector control	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
LO	1	Presence of a control plan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
LO	1	Surveillance of pathogenic agent in region of interest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	
LO	1	PHLS added value	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Capacity for early detection via data pooling	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Capacity to provide extra awareness at	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		national level																										
LO	1	Capacity to recognize threats requiring coordinated action	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Capacity to aid knowledge generation	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Improvement of programme evaluation	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	knowledge advancement via pooling of resources	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Helps raise national standards	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Helps develop europe-wide surveillance and prevention	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
LO	1	Effectiveness of national and international surveillance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	
PH	1	Psychological	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	PHC-

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		impact in humans																										02
PH	1	Co-infection in humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	PHC-02
PH	1	Public Health - degree of exposure	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	PHC-01
PH	1	Likely incidence if introduced or re-emerged	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-04
RE	1	Occurrence in food / slaughter houses	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	0	-	-	-	-	-	-	-	REC-01
RE	1	Long term effects on comm. Disease	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	
RE	1	low incidence only maintained by PH act.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	
RE	1	Identification of reservoir or asymptomatic species	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	0	-	-	-	-	-	-	-	
RE	1	Identification of vector species and existance of surveillance or study	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	0	-	-	-	-	-	-	-	
RE	1	Impact of CC	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	0	-	-	-	-	-	-	-	REC-01
RE	1	Ability of pathogen to	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
		mutate and adapt																										
RE	1	Combined disease risk and probability of infection	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	Endemicity of disease due to CC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	Immunogenicity humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	CC impact vectors and animal hosts	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	Endemicity risk animals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	
RE	1	Endemicity risk humans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-02
RE	1	Seasonality of disease	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	Size of reservoir	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	REC-01
RE	1	Geographical source of disease	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-		REC-01
RE	1	Evolutive characteristics of pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	REC-02
RE	1	Presence/absence of vector/reservoir in region of interest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	REC-01

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
RE	1	Specificity of pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	REC-02
RE	1	Persistence environment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	REC-01
RE	1	Current climatic conditions	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Geographic proximity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of annual temperature increase on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of summer ppt decrease on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of summer ppt increase on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of summer temperature decrease on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of summer temperature increase on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	New criteria
RE	1	Impact of winter ppt decrease on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of winter ppt increase on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of winter temperature decrease on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Impact of winter temperature increase on pathogen	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Number of ways pathogen can enter region of interest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Pathogenic taxonomic group	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Presence of definitive host species	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Presence of suitable vector in region of interest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01
RE	1	Type of climate pathogen can tolerate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	REC-01

Cat	#	Criteria	*Carter 1991	*Rushdy et al 1998	Weinberg et al 1999	Doherty 2000	Horby et al 2001	*Valenciano 2002	WHO 2003 (Dubrovnik pledge)	WHO 2006	Doherty 2006	McKenzie et al 2007	*Krause et al 2008 (a&b)	Cardoen et al 2009	Capek 2010	Havelaar et al 2010	Pavlin et al 2010	Ruzante et al 2010	Balabanova et al 2011	Humblet et al 2012	Ng & Sargeant 2012, 2013	Ng & Sargeant 2013	Cediel et al 2013	Cox et al 2013	Del rio Vilas 2013	Brookes et al 2014	Kadohira 2015	**New criteria**
SP	1	Discontent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	SIC-02

*Cat, Category: PH – public health; LO – logistics; SP – Social perception; RE – Risk and epidemiology; AE – Animal and environmental health; EC – economics

number of studies in which similar criteria were used

Table XXXV. Individual stakeholder weights for all criteria ordered by importance for the "Research" intervention domain

S1		S2		S3		S4		S5		S6		S7		S8		S9		S10	
SOC-01	11	SOC-03	15	PHC-02	10	PHC-02	15	REC-01	10	REC-01	9	PHC-02	11	SOC-01	16	PHC-04	6	PHC-01	28
SOC-03	11	PHC-02	12	REC-02	10	REC-02	10	SOC-02	10	REC-02	9	PHC-01	9	SOC-02	16	REC-04	6	REC-02	10
REC-01	9	PHC-01	9	REC-03	10	REC-04	10	SOC-03	10	PHC-02	9	SOC-02	8	SOC-03	10	AEC-03	6	REC-01	9
REC-02	9	PHC-03	9	SIC-01	9	SOC-03	10	PHC-02	5	PHC-01	8	REC-02	7	SOC-05	5	ECC-03	6	ECC-01	8
REC-03	9	REC-02	6	SIC-02	6	REC-01	5	PHC-03	5	REC-03	8	PHC-03	6	AEC-01	4	SOC-04	6	PHC-02	6
PHC-01	6	REC-03	6	SOC-02	6	PHC-03	5	SIC-01	5	AEC-03	7	SIC-01	6	AEC-02	4	SOC-05	6	ECC-02	5
PHC-02	6	ECC-01	5	PHC-01	5	REC-03	5	SIC-02	5	AEC-01	7	SOC-01	6	AEC-03	4	REC-01	5	PHC-03	4
PHC-03	6	ECC-02	5	PHC-03	5	AEC-02	5	REC-04	5	AEC-02	7	REC-01	5	REC-01	3	PHC-03	5	AEC-01	4
SOC-02	4	ECC-03	5	PHC-04	5	AEC-03	5	AEC-01	5	PHC-03	5	PHC-04	4	PHC-01	3	SIC-02	5	REC-04	4
AEC-02	4	REC-01	4	AEC-03	5	ECC-03	5	AEC-02	5	REC-04	5	SIC-02	4	PHC-02	3	REC-02	5	AEC-02	4
SIC-01	4	REC-04	4	SOC-03	5	SOC-01	5	AEC-03	5	SOC-03	5	REC-03	4	PHC-03	3	REC-03	5	SIC-02	3
REC-04	3	AEC-01	3	ECC-01	4	SIC-02	4	ECC-01	5	SOC-04	5	REC-04	4	PHC-04	3	SOC-03	5	ECC-03	3
AEC-01	3	AEC-02	3	ECC-03	4	SOC-02	4	SOC-01	5	PHC-04	4	AEC-03	4	SIC-01	3	PHC-02	4	REC-03	3
AEC-03	3	AEC-03	3	REC-01	3	PHC-01	3	ECC-02	4	ECC-01	3	SOC-03	4	SIC-02	3	SIC-01	4	AEC-03	3
SOC-04	3	SOC-04	3	REC-04	3	ECC-01	3	PHC-04	3	ECC-03	2	AEC-02	4	REC-02	3	AEC-02	4	SOC-03	3
PHC-04	2	SIC-01	3	AEC-01	3	PHC-04	2	REC-02	3	SOC-01	2	ECC-01	4	REC-03	3	ECC-01	4	PHC-04	2
ECC-01	2	SIC-02	3	AEC-02	3	ECC-02	2	SOC-04	3	SOC-02	2	ECC-02	4	REC-04	3	ECC-02	4	SIC-01	2
ECC-02	2	SOC-01	1	ECC-02	2	SIC-01	1	PHC-01	2	ECC-02	2	ECC-03	3	ECC-01	3	SOC-01	4	SOC-01	1
SIC-02	2	SOC-02	1	SOC-01	2	SOC-04	1	REC-03	2	SIC-01	2	AEC-01	3	ECC-02	3	SOC-02	4	SOC-05	1
ECC-03	2	PHC-04	0	SOC-04	2	AEC-01	0	SOC-05	2	SIC-02	2	SOC-04	1	SOC-04	3	PHC-01	3	SOC-02	1
SOC-05	1	SOC-05	0	SOC-05	2	SOC-05	0	ECC-03	1	SOC-05	2	SOC-05	1	ECC-03	2	AEC-01	3	SOC-04	0
	100		100		100		100		100		100		100		100		100		100

Table XXXVI. Individual stakeholder weights for all criteria ordered by importance for the surveillance intervention domain

S1		S2		S3		S4		S5		S6		S7		S8		S9		S10	
REC-03	12	REC-02	13	PHC-02	10	PHC-02	15	REC-01	10	PHC-01	7	REC-02	11	REC-01	17	PHC-03	6	PHC-01	15
SOC-01	12	PHC-02	12	REC-02	10	REC-02	10	PHC-01	10	PHC-02	7	PHC-02	10	REC-02	17	REC-04	6	AEC-01	12
SOC-03	12	PHC-01	9	REC-03	10	REC-04	10	SOC-01	10	AEC-01	6	REC-01	9	REC-03	16	SOC-05	6	ECC-01	11
REC-01	8	PHC-03	9	SIC-01	9	SOC-01	10	SOC-02	10	AEC-03	6	PHC-01	9	PHC-01	14	PHC-01	5	REC-01	10
PHC-01	8	SOC-02	9	SIC-02	6	REC-01	5	PHC-02	5	AEC-02	6	REC-03	8	SOC-01	9	PHC-04	5	PHC-03	6
PHC-03	7	REC-03	6	SOC-02	6	PHC-01	5	SIC-01	5	PHC-03	6	SOC-01	7	SOC-05	7	SIC-02	5	AEC-02	6
REC-02	6	SIC-02	5	PHC-01	5	PHC-03	5	SIC-02	5	REC-01	6	PHC-03	5	AEC-01	3	REC-02	5	SOC-01	6
REC-04	5	SOC-01	4	PHC-03	5	REC-03	5	REC-04	5	REC-02	6	SOC-02	5	AEC-02	3	REC-03	5	REC-04	5
PHC-02	4	SOC-03	4	PHC-04	5	ECC-03	5	AEC-01	5	REC-03	6	SOC-03	4	AEC-03	3	AEC-02	5	SOC-05	4
AEC-01	4	REC-01	3	AEC-03	5	SOC-03	5	AEC-02	5	REC-04	6	AEC-02	4	PHC-02	1	AEC-03	5	SIC-02	4
AEC-02	3	AEC-01	3	SOC-03	5	AEC-02	4	AEC-03	5	ECC-01	5	AEC-03	4	PHC-03	1	ECC-03	5	REC-02	3
AEC-03	3	ECC-01	3	ECC-01	4	AEC-03	4	ECC-01	5	ECC-03	5	ECC-01	4	PHC-04	1	SOC-02	5	ECC-02	3
SOC-05	3	AEC-02	3	ECC-03	4	SIC-01	3	SOC-03	5	SOC-01	4	ECC-02	4	SIC-01	1	SOC-03	5	SOC-03	3
SIC-01	3	AEC-03	3	REC-01	3	ECC-01	3	PHC-03	3	SOC-02	4	REC-04	3	SIC-02	1	SOC-04	5	PHC-02	3
SIC-02	3	ECC-02	3	REC-04	3	SOC-04	3	REC-02	3	SOC-03	4	AEC-01	3	ECC-01	1	REC-01	4	REC-03	2
ECC-01	2	ECC-03	3	AEC-01	3	SIC-02	2	SOC-04	3	SOC-04	4	ECC-03	3	ECC-02	1	PHC-02	4	AEC-03	2
ECC-02	2	REC-04	3	AEC-02	3	AEC-01	2	PHC-04	2	ECC-02	4	SIC-01	3	ECC-03	1	SIC-01	4	SIC-01	2
ECC-03	2	SOC-04	2	ECC-02	2	ECC-02	2	REC-03	2	PHC-04	3	SIC-02	3	SOC-02	1	AEC-01	4	SOC-04	2
SOC-02	2	SOC-05	1	SOC-01	2	SOC-02	2	SOC-05	2	SOC-05	3	SOC-04	2	SOC-03	1	ECC-02	4	PHC-04	1
SOC-04	2	PHC-04	0	SOC-04	2	PHC-04	0	ECC-02	0	SIC-01	2	SOC-05	2	SOC-04	1	SOC-01	4	ECC-03	1
PHC-04	1	SIC-01	0	SOC-05	2	SOC-05	0	ECC-03	0	SIC-02	2	PHC-04	1	REC-04	0	ECC-01	3	SOC-02	1
	100		100		100		100		100		100		100		100		100		100

Table XXXVII. Individual stakeholder weights for all criteria ordered by importance for the prevention and control intervention domain

S1		S2		S3		S4		S5		S6		S7		S8		S9		S10	
SOC-01	11	SOC-02	13	PHC-02	10	SOC-02	15	REC-01	10	AEC-01	6	PHC-02	12	SOC-01	12	REC-01	6	PHC-01	14
REC-01	9	PHC-02	12	REC-02	10	PHC-02	13	SOC-02	10	AEC-02	6	PHC-01	11	SOC-02	12	PHC-03	6	PHC-03	12
SOC-02	9	PHC-03	9	REC-03	10	REC-02	10	PHC-01	8	AEC-03	6	REC-02	9	SIC-01	10	PHC-01	5	REC-01	9
PHC-03	8	REC-01	8	SIC-01	9	REC-04	10	ECC-01	8	ECC-01	6	SOC-02	9	SIC-02	10	PHC-04	5	ECC-01	9
REC-02	8	REC-02	8	SIC-02	6	ECC-01	6	SIC-01	8	ECC-03	6	REC-01	6	PHC-01	6	SIC-02	5	SOC-02	8
REC-03	8	REC-03	8	SOC-02	6	REC-01	5	SIC-02	8	REC-01	5	SOC-01	6	PHC-02	6	REC-02	5	PHC-02	5
PHC-01	6	SOC-04	6	PHC-01	5	PHC-01	5	SOC-01	7	PHC-01	5	SIC-01	5	PHC-03	6	REC-04	5	REC-04	5
REC-04	6	PHC-01	6	PHC-03	5	PHC-03	5	PHC-03	5	PHC-02	5	SIC-02	5	REC-01	5	AEC-03	5	SOC-04	5
SOC-03	6	SIC-01	5	PHC-04	5	REC-03	5	AEC-01	5	PHC-03	5	REC-03	5	REC-02	5	ECC-03	5	ECC-02	5
PHC-02	4	AEC-01	3	AEC-03	5	SIC-02	4	AEC-02	5	REC-02	5	REC-04	5	REC-03	5	SOC-01	5	REC-02	4
AEC-01	4	AEC-02	3	SOC-03	5	AEC-02	4	AEC-03	5	REC-03	5	SOC-03	5	REC-04	5	SOC-02	5	SOC-01	4
AEC-02	4	AEC-03	3	ECC-01	4	AEC-03	4	ECC-02	5	REC-04	5	PHC-03	5	AEC-02	4	SOC-03	5	PHC-04	4
AEC-03	3	SOC-01	3	ECC-03	4	PHC-04	2	PHC-04	3	ECC-02	5	PHC-04	3	AEC-03	4	SOC-04	5	SIC-02	3
SOC-04	3	SOC-03	3	REC-01	3	AEC-01	2	PHC-02	2	SOC-01	5	SOC-04	3	PHC-04	2	SOC-05	5	AEC-01	3
SIC-01	3	PHC-04	3	REC-04	3	ECC-02	2	REC-03	2	SOC-02	5	SOC-05	3	AEC-01	2	PHC-02	4	SIC-01	2
SIC-02	3	REC-04	3	AEC-01	3	ECC-03	2	REC-04	2	SIC-01	4	AEC-02	2	ECC-01	1	SIC-01	4	REC-03	2
PHC-04	2	ECC-01	2	AEC-02	3	SOC-01	2	ECC-03	2	SIC-02	4	AEC-03	2	ECC-02	1	REC-03	4	SOC-05	2
ECC-01	2	ECC-02	2	ECC-02	2	SOC-03	2	SOC-03	2	PHC-04	4	ECC-01	2	ECC-03	1	AEC-01	4	ECC-03	2
ECC-02	2	ECC-03	2	SOC-01	2	SIC-01	1	SOC-04	2	SOC-03	4	ECC-02	2	SOC-03	1	AEC-02	4	AEC-02	1
ECC-03	2	SIC-02	0	SOC-04	2	SOC-04	1	REC-02	1	SOC-04	3	AEC-01	2	SOC-04	1	ECC-01	4	SOC-03	1
SOC-05	2	SOC-05	0	SOC-05	2	SOC-05	0	SOC-05	1	SOC-05	3	ECC-03	2	SOC-05	1	ECC-02	4	AEC-03	1
	100		100		100		100		100		100		100		100		100		100

Table XXXVIII. Weight stability intervals from sensitivity analysis of all stakeholders for the surveillance domain

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
PHC-01	5 (0-100)	6 (0-100)	5 (0-100)	5 (0-100)	8 (0-100)	5 (0-100)	11 (0-100)	6 (1.5-100)	5 (0-100)	14 (0-100)
PHC-02	4(3-8)	12 (7-25)	10 (4-15)	13 (11.5-23)	2 (0-13)	5 (0.5-18)	12 (3.5-16)	6 (2.5-9)	4 (1.5-14)	5 (0-7)
PHC-03	8(7-100)	9 (8-100)	5 (4.5-100)	5 (3-11.5)	5 (0-100)	5 (4.5-100)	5 (3-100)	6 (1.5-10)	6 (0-100)	12 (0-100)
PHC-04	2 (0-100)	3 (0-100)	5 (0-100)	2 (0-100)	3 (0-100)	4 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	4 (0-100)
SIC-01	3(2-23.5)	5 (3.5-22)	9 (8.5-15.5)	1 (0-8)	8 (0-20)	4 (3.5-20)	5 (3-16)	10 (5-14)	4 (0-16)	2 (0-20)
SIC-02	3(0-23.5)	0 (0-100)	6 (0-13)	4 (0-17)	8 (0-20)	4 (0-19)	5 (0-16)	10 (0-14)	5 (0-17)	3 (0-20)
REC-01	9(8-19)	8 (7-21.5)	3 (2.5-15)	5 (3-10.5)	10 (3.5-25)	5 (4.5-18)	6 (4.5-11)	5 (1.5-8.5)	6 (0-17)	9 (0-11)
REC-02	8 (0-14)	8 (0-16.5)	10 (1.5-17)	10 (0-17)	1 (0-12)	5 (0-13)	9 (0-12)	5 (0.5-16)	5 (0-12)	4 (0-5)
REC-03	8(1-8)	8 (0-9)	10 (2.5-10)	5 (0-6.5)	2 (0-8)	5 (0-5)	5 (2-6)	5 (1-8)	4 (0-9)	2 (0.5-13)
REC-04	6(0-100)	3 (0-100)	3 (0-100)	10 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)
AEC-01	4(0-100)	3 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	2 (0-100)	4 (0-100)	3 (0-100)
AEC-02	4(0-4)	3 (0-5)	3 (0-3)	4 (0-5)	5 (0-11)	6 (0-6.5)	2 (0-4)	4 (0-7)	4 (0-7)	1 (0-14)
AEC-03	3(0-100)	3 (0-100)	5 (0-100)	4 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	4 (0-100)	5 (0-100)	1 (0-100)
ECC-01	2(1-7)	2 (0-100)	4 (0-100)	6 (4-100)	8 (2.5-100)	6 (0.5-100)	2 (0-100)	1 (0-100)	4 (1-100)	9 (0-100)
ECC-02	2(1-7)	2 (0-100)	2 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	2 (0-100)	1 (0-100)	4 (0-100)	5 (0-100)
ECC-03	2(0-100)	2 (0-100)	4 (0-100)	2 (0-100)	2 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	5 (0-100)	2 (0-100)
SOC-01	10 (0-100)	3 (0-4)	2 (0-2)	2 (0-15)	7 (1.5-13)	5 (0-5)	6 (0-7)	12 (7.5-15.5)	5 (2.5-11)	4 (0-16)
SOC-02	9(0-9)	13 (4-15)	6 (0-6)	15 (8.5-16)	10 (0-17)	5 (0-5.5)	9 (6-11)	12 (5-15)	5 (0-9)	8 (6.5-23.5)
SOC-03	6 (0-6)	3 (0-8.5)	5 (0-11)	2 (0-4)	2 (0-7)	4 (0-9)	5 (1-13.5)	1 (0-5)	5 (0-7)	1 (0-12)
SOC-04	3 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	2 (0-100)	3 (0-100)	3 (0-100)	1 (0-100)	5 (0-100)	5 (0-100)
SOC-05	2 (1-100)	0 (0-100)	2 (1.5-100)	0 (0-100)	1 (0-100)	3 (2.5-100)	3 (1-100)	1 (0-5)	5 (0-100)	2 (0-100)

S1-S10 – denotes stakeholders 1 through 10; Stakeholder assigned weights are given for all criteria followed by the stability interval in parentheses over which the ranking order for the 1st position items is maintained. PHC – Public Health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC - Economic criteria; SOC – Strategic and operational criteria

Table XXXIX. Weight stability intervals from sensitivity analysis of all stakeholders for the prevention & control domain

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
PHC-01	5 (0-100)	6 (0-100)	5 (0-100)	5 (0-100)	8 (0-100)	5 (0-100)	11 (0-100)	6 (1.5-100)	5 (0-100)	14 (0-100)
PHC-02	4(3-8)	12 (7-25)	10 (4-15)	13 (11.5-23)	2 (0-13)	5 (0.5-18)	12 (3.5-16)	6 (2.5-9)	4 (1.5-14)	5 (0-7)
PHC-03	8(7-100)	9 (8-100)	5 (4.5-100)	5 (3-11.5)	5 (0-100)	5 (4.5-100)	5 (3-100)	6 (1.5-10)	6 (0-100)	12 (0-100)
PHC-04	2 (0-100)	3 (0-100)	5 (0-100)	2 (0-100)	3 (0-100)	4 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	4 (0-100)
SIC-01	3(2-23.5)	5 (3.5-22)	9 (8.5-15.5)	1 (0-8)	8 (0-20)	4 (3.5-20)	5 (3-16)	10 (5-14)	4 (0-16)	2 (0-20)
SIC-02	3(0-23.5)	0 (0-100)	6 (0-13)	4 (0-17)	8 (0-20)	4 (0-19)	5 (0-16)	10 (0-14)	5 (0-17)	3 (0-20)
REC-01	9(8-19)	8 (7-21.5)	3 (2.5-15)	5 (3-10.5)	10 (3.5-25)	5 (4.5-18)	6 (4.5-11)	5 (1.5-8.5)	6 (0-17)	9 (0-11)
REC-02	8 (0-14)	8 (0-16.5)	10 (1.5-17)	10 (0-17)	1 (0-12)	5 (0-13)	9 (0-12)	5 (0.5-16)	5 (0-12)	4 (0-5)
REC-03	8(1-8)	8 (0-9)	10 (2.5-10)	5 (0-6.5)	2 (0-8)	5 (0-5)	5 (2-6)	5 (1-8)	4 (0-9)	2 (0.5-13)
REC-04	6(0-100)	3 (0-100)	3 (0-100)	10 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)
AEC-01	4(0-100)	3 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	2 (0-100)	4 (0-100)	3 (0-100)
AEC-02	4(0-4)	3 (0-5)	3 (0-3)	4 (0-5)	5 (0-11)	6 (0-6.5)	2 (0-4)	4 (0-7)	4 (0-7)	1 (0-14)
AEC-03	3(0-100)	3 (0-100)	5 (0-100)	4 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	4 (0-100)	5 (0-100)	1 (0-100)
ECC-01	2(1-7)	2 (0-100)	4 (0-100)	6 (4-100)	8 (2.5-100)	6 (0.5-100)	2 (0-100)	1 (0-100)	4 (1-100)	9 (0-100)
ECC-02	2(1-7)	2 (0-100)	2 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	2 (0-100)	1 (0-100)	4 (0-100)	5 (0-100)
ECC-03	2(0-100)	2 (0-100)	4 (0-100)	2 (0-100)	2 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	5 (0-100)	2 (0-100)
SOC-01	10 (0-100)	3 (0-4)	2 (0-2)	2 (0-15)	7 (1.5-13)	5 (0-5)	6 (0-7)	12 (7.5-15.5)	5 (2.5-11)	4 (0-16)
SOC-02	9(0-9)	13 (4-15)	6 (0-6)	15 (8.5-16)	10 (0-17)	5 (0-5.5)	9 (6-11)	12 (5-15)	5 (0-9)	8 (6.5-23.5)
SOC-03	6 (0-6)	3 (0-8.5)	5 (0-11)	2 (0-4)	2 (0-7)	4 (0-9)	5 (1-13.5)	1 (0-5)	5 (0-7)	1 (0-12)
SOC-04	3 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	2 (0-100)	3 (0-100)	3 (0-100)	1 (0-100)	5 (0-100)	5 (0-100)
SOC-05	2 (1-100)	0 (0-100)	2 (1.5-100)	0 (0-100)	1 (0-100)	3 (2.5-100)	3 (1-100)	1 (0-5)	5 (0-100)	2 (0-100)

S1-S10 – denotes stakeholders 1 through 10; Stakeholder assigned weights are given for all criteria followed by the stability interval in parentheses over which the ranking order for the 1st position items is maintained. PHC – Public Health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC - Economic criteria; SOC – Strategic and operational criteria

SR1 - Supporting references used to assess disease scores for the pilot prioritization

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APPENDIX 2: SUPPORTING INFORMATION FOR CHAPTER 3

Multi-stakeholder decision aid for improved prioritization of the public health impact of climate sensitive infectious diseases

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List of Supplementary Materials:

Table XL. Measurement units for model criteria

Criteria	Measurement units
PHC-01 – Current incidence of human cases in country	0: Nil; 1: Very Low; 2: Low; 3: Moderate; 4: High; 5: very high; 6: Unknown
PHC-02 – Severity of the disease (both physically and mentally)	0: Nil; 1: Low severity; 2: Moderate severity; 3: High severity; 4: Very high severity (risk of mortality)
PHC-03 – Vulnerable groups	0: All are vulnerable; 1: Existence of higher risk groups (e.g. 0-5yrs)
PHC-04 – Potential to increase social inequality *	0: No effect on social inequality; 1: Likely to exacerbate social inequality
PHC-05 – New disease	0: Existing disease; 1: New disease for country
SIC-01 – Risk perception of the public	1: Low perceived importance; 2: Moderate importance; 3: High importance
SIC-02 – General level of knowledge, attitude and behaviour of the public	1: Little or no knowledge ; 2: Moderate knowledge (general idea of symptoms); 3: High knowledge (can recognize symptoms and aware of transmission and treatment)
SIC-03 – Risk perception of health workers †	1: Low perceived importance; 2: Moderate importance; 3: High importance
SIC-04 – Risk perception of decision makers†	1: Low perceived importance; 2: Moderate importance; 3: High importance
SIC-05 – International position with regards to the disease †	1: Low perceived importance; 2: Moderate importance; 3: High importance
REC-01 – Existence of favourable conditions for disease transmission	1: Low risk (climate not suitable, no vector and no reservoir hosts); 2: Moderate risk (one of components present, either suitable climate, vector or reservoir host); 3: High risk (all components present – suitable climate, vector and reservoir host - or current or historic transmission)
REC-02 – Epidemic potential	1: Low risk; 2: high risk
REC-03 – Current global trend of disease over last 5 years	1: Stable – little to no recent local or global change in transmission; 2: unstable – recent global changes in transmission; 3: very unstable – recent local changes in transmission
REC-04 – Proportion of susceptible population	1 : very low 0-5%; 2: low 5-10%; 3: moderate 10-25%; 4: high 25-50%; 5: very high 50+
AEC-01 – Incidence of animal cases	0: not transmissible to animals; 1 : very low (<5%); 2: low (5-10%); 3: moderate (10-25%); 4: high (25-50%); 5: very high (50+); 6: unknown prevalence
AEC-02 – Severity of disease	0: Not applicable; 1: Low severity; 2: Moderate severity; 3: High severity; 4: Very high severity (risk of mortality)
AEC-03 – Environmental or animal reservoir stage	1: Low risk – no independent stages that can survive in environment, water or reservoir hosts; 2: higher risk – existence of independent stages that can survive in environment, water or reservoir hosts.

Criteria	Measurement units
ECC-01 – Cost to the government	1: low costs; 2: moderate costs; 3: high costs
ECC-02 – Cost to private sector (and NGOs) †	1: low costs; 2: moderate costs; 3: high costs
ECC-03 – Cost to individuals (and families) †	1: low costs; 2: moderate costs; 3: high costs
SOC-01 – Capacity to detect and diagnose	0 : no tests, symptoms difficult to recognize; 1: distinct symptoms or existence of tests
SOC-02 – Existence and effectiveness of current treatments	0: no existing treatment; 1: partially effective treatment; 2: highly effective treatment available
SOC-03 – Level of scientific knowledge of the disease	1: low – very little knowledge; 2: moderate – partial yet incomplete knowledge of disease symptoms, transmission, risk factors and treatment; 3: high – symptoms, transmission, risk factors and treatment well known
SOC-04 – Optimization opportunities	0: no opportunities; 1: potential opportunities
SOC-05– Reportable disease	0: not reportable; 1: nationally or internationally reportable
SOC-06 – Access to treatment†	1: little to no access to treatment; 2: treatment easily accessible
SOC-07 – Adequate conditions to treat the disease †	1: conditions lacking; 2: acceptable conditions

* Criteria added in Quebec (Canada); † Criteria added or modified in Burkina Faso (Africa)

Table XLI. Weight stability Interval by criteria for Burkina Faso stakeholders

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
PHC-01	20 (16-100)	16 (1-100)	2 (0-2)	8 (0-100)	3 (0-21)	6 (5-100)	7 (0-11)	4 (0-12)	14 (8-100)	11 (7-100)
PHC-02	12 (5.5-100)	12 (5-100)	1 (0.5-100)	4 (1-100)	14 (0-100)	5 (0-5)	10 (0-100)	2 (0-100)	0(0-100)	12 (0-100)
PHC-03	4 (0-8.5)	8 (0-20)	1 (0.5-100)	3 (0-11.5)	2 (0-100)	3 (0-3)	4 (0-100)	1 (0-100)	0(0-100)	6 (0-10)
PHC-05	4 (0-100)	4 (0-100)	1 (0-100)	7 (0-100)	1 (0-100)	6 (0-100)	1 (0-100)	1 (0-100)	1(0-100)	1 (0-100)
SIC-01	1(0-8.5)	2 (0-21.5)	1 (0.5-100)	3 (0-16.5)	6 (0-100)	3 (0-3.5)	5 (0-100)	5 (0-100)	7(0-8.5)	6 (0-12)
SIC-02	1 (0-10)	3 (0-12.5)	2 (0-2)	1 (0-5.5)	1 (0-18)	4 (3.5-100)	0 (0-100)	1 (0-9)	1(0-100)	1 (0-17)
SIC-03	1 (0-100)	2(0-100)	3 (2.5-100)	4 (0-100)	1 (0-100)	4 (0-4)	0 (0-100)	1(0-100)	1 (0-2)	1 (0-100)
SIC-04	5 (0-9.5)	2(0-15)	2 (1.5-100)	3 (0-11)	3 (0-100)	3 (0-3)	3 (0-100)	2 (0-100)	3 (0-9)	0 (0-100)
SIC-05	2 (0-6.5)	1(0-9)	2 (0-100)	1 (0-5)	14 (0-100)	4 (3.5-100)	2 (0-100)	2 (0-100)	5 (3.5-100)	6 (0-10)
REC-01	8(0-100)	8 (0-100)	2 (0-100)	4 (0-100)	8 (0-100)	4 (0-100)	6 (0-100)	5 (0-100)	7(0-100)	2 (0-100)
REC-02	6(0-100)	4 (0-100)	2 (0-100)	3 (0-100)	2 (0-100)	3 (0-100)	0 (0-100)	4 (0-100)	1(0-100)	2 (0-100)
REC-03	4(0-20.5)	6(0-23)	3 (0-3)	1 (0-9.5)	1 (0-20.50)	4 (3.5-100)	0 (0-100)	2 (0-12)	1(0-100)	2 (0-29)
REC-04	2 (0-100)	2 (0-100)	3 (0-100)	5 (0-100)	6 (0-100)	4 (0-100)	7 (0-100)	6 (0-100)	7(0-100)	4 (0-100)
AEC-01	0.5 (0-100)	2(0-100)	2 (0-2)	6 (0-100)	2 (0-18)	4 (4-100)	2 (0-5)	1 (0-8)	2(0-100)	2 (0-100)
AEC-02	0.5 (0-17.5)	4(0-21)	1 (0-1)	4 (0-12)	2 (0-24)	3 (2.5-45)	2 (0-8)	1 (0-13)	2(0-39)	2 (0-29)
AEC-03	4 (0-100)	4(0-100)	2 (0-100)	5 (0-100)	4 (0-100)	3 (0-100)	6 (0-100)	6 (0-100)	8 (0-100)	4 (0-100)
ECC-01	5 (0-11)	1(0-17)	10 (9.5-100)	1 (0-11)	11 (0-100)	7 (0-7)	7 (1.5-100)	13 (2-100)	2(0-9)	0 (0-100)
ECC-02	5 (0-11)	1(0-17)	5 (4.5-100)	1 (0-11)	2 (0-100)	4 (0-4)	1 (0-100)	2 (0-100)	3(0-10)	0 (0-100)
ECC-03	4 (0-100)	3(0-100)	10 (0-100)	9 (0-100)	7 (0-100)	7 (0-100)	7 (0-100)	12 (0-100)	11 (0-100)	14 (0-100)
SOC-01	0.5 (0-100)	6(0-100)	13 (0-100)	11 (0-100)	3 (0-100)	3 (0-100)	10 (0-100)	4 (0-100)	8 (0-100)	0 (0-100)
SOC-02	0.5 (0-12.5)	3(0-15)	7 (0-7)	3 (0-9)	2 (0-21.5)	4 (3.5-100)	6 (0-12)	5 (0-15)	4 (1.5-100)	5 (0-24)
SOC-03	4 (0-11)	1(0-9.5)	7 (0-7)	3 (0-7)	0 (0-23)	4 (3.5-100)	2 (0-16)	5 (0-16)	3 (1-100)	3 (0-15.5)
SOC-04	3 (0-100)	1 (0-100)	5 (0-100)	2 (0-100)	0 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	3 (0-100)	3 (0-100)
SOC-05	1 (0-100)	1(0-100)	7 (6.5-100)	2 (0-100)	1 (0-100)	4 (0-4)	5 (0-100)	9 (0-100)	4 (0-5)	9 (0-100)
SOC-06	0.5 (0-24)	0 (0-100)	4 (0-14)	2 (0-15)	0 (0-26)	2 (0-15)	0 (0-100)	0(0-100)	1 (0-15)	0 (0-100)
SOC-07	0.5 (0-24)	1 (0-26)	2 (0-12)	2 (0-15)	3 (0-28.5)	2 (0-15)	5 (0-19)	3 (0-17)	3 (0-16.5)	5 (0-20.5)

S1-S10 – denotes stakeholders 1 through 10. Stakeholder assigned weights are given for all criteria followed by the stability interval in parentheses over which the ranking order for the 1st position items is maintained. PHC – Public Health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC - Economic criteria; SOC – Strategic and operational criteria.

Table XLII. Weight stability Interval by criteria for Quebec stakeholders

Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
PHC-01	5 (0-100)	6 (0-100)	5 (0-100)	5 (0-100)	8 (0-100)	5 (0-100)	11 (0-100)	6 (1.5-100)	5 (0-100)	14 (0-100)
PHC-02	4(3-8)	12 (7-25)	10 (4-15)	13 (11.5-23)	2 (0-13)	5 (0.5-18)	12 (3.5-16)	6 (2.5-9)	4 (1.5-14)	5 (0-7)
PHC-03	8(7-100)	9 (8-100)	5 (4.5-100)	5 (3-11.5)	5 (0-100)	5 (4.5-100)	5 (3-100)	6 (1.5-10)	6 (0-100)	12 (0-100)
PHC-04	2 (0-100)	3 (0-100)	5 (0-100)	2 (0-100)	3 (0-100)	4 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	4 (0-100)
SIC-01	3(2-23.5)	5 (3.5-22)	9 (8.5-15.5)	1 (0-8)	8 (0-20)	4 (3.5-20)	5 (3-16)	10 (5-14)	4 (0-16)	2 (0-20)
SIC-02	3(0-23.5)	0 (0-100)	6 (0-13)	4 (0-17)	8 (0-20)	4 (0-19)	5 (0-16)	10 (0-14)	5 (0-17)	3 (0-20)
REC-01	9(8-19)	8 (7-21.5)	3 (2.5-15)	5 (3-10.5)	10 (3.5-25)	5 (4.5-18)	6 (4.5-11)	5 (1.5-8.5)	6 (0-17)	9 (0-11)
REC-02	8 (0-14)	8 (0-16.5)	10 (1.5-17)	10 (0-17)	1 (0-12)	5 (0-13)	9 (0-12)	5 (0.5-16)	5 (0-12)	4 (0-5)
REC-03	8(1-8)	8 (0-9)	10 (2.5-10)	5 (0-6.5)	2 (0-8)	5 (0-5)	5 (2-6)	5 (1-8)	4 (0-9)	2 (0.5-13)
REC-04	6(0-100)	3 (0-100)	3 (0-100)	10 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)	5 (0-100)
AEC-01	4(0-100)	3 (0-100)	3 (0-100)	2 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	2 (0-100)	4 (0-100)	3 (0-100)
AEC-02	4(0-4)	3 (0-5)	3 (0-3)	4 (0-5)	5 (0-11)	6 (0-6.5)	2 (0-4)	4 (0-7)	4 (0-7)	1 (0-14)
AEC-03	3(0-100)	3 (0-100)	5 (0-100)	4 (0-100)	5 (0-100)	6 (0-100)	2 (0-100)	4 (0-100)	5 (0-100)	1 (0-100)
ECC-01	2(1-7)	2 (0-100)	4 (0-100)	6 (4-100)	8 (2.5-100)	6 (0.5-100)	2 (0-100)	1 (0-100)	4 (1-100)	9 (0-100)
ECC-02	2(1-7)	2 (0-100)	2 (0-100)	2 (0-100)	5 (0-100)	5 (0-100)	2 (0-100)	1 (0-100)	4 (0-100)	5 (0-100)
ECC-03	2(0-100)	2 (0-100)	4 (0-100)	2 (0-100)	2 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	5 (0-100)	2 (0-100)
SOC-01	10 (0-100)	3 (0-4)	2 (0-2)	2 (0-15)	7 (1.5-13)	5 (0-5)	6 (0-7)	12 (7.5-15.5)	5 (2.5-11)	4 (0-16)
SOC-02	9(0-9)	13 (4-15)	6 (0-6)	15 (8.5-16)	10 (0-17)	5 (0-5.5)	9 (6-11)	12 (5-15)	5 (0-9)	8 (6.5-23.5)
SOC-03	6 (0-6)	3 (0-8.5)	5 (0-11)	2 (0-4)	2 (0-7)	4 (0-9)	5 (1-13.5)	1 (0-5)	5 (0-7)	1 (0-12)
SOC-04	3 (0-100)	6 (0-100)	2 (0-100)	1 (0-100)	2 (0-100)	3 (0-100)	3 (0-100)	1 (0-100)	5 (0-100)	5 (0-100)
SOC-05	2 (1-100)	0 (0-100)	2 (1.5-100)	0 (0-100)	1 (0-100)	3 (2.5-100)	3 (1-100)	1 (0-5)	5 (0-100)	2 (0-100)

S1-S10 – denotes stakeholders 1 through 10. Stakeholder assigned weights are given for all criteria followed by the stability interval in parentheses over which the ranking order for the 1st position items is maintained. PHC – Public Health criteria; SIC – Social impact criteria; REC – Risk and epidemiology criteria; AEC – Animal and environmental health criteria; ECC - Economic criteria; SOC – Strategic and operational criteria

SR2 - References used in the disease assessment scores for the pilot disease prioritization

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APPENDIX 3: SUPPORTING INFORMATION FOR CHAPTER 4

Knowledge and protective measures adopted by Quebec residents against mosquitoes and West Nile virus

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List of Supplementary Materials:

Questionnaire (français)
Questionnaire (English)

Questionnaire (français)

“S’adapter aux risques de maladies infectieuses liées au climat”

Chercheure-Étudiante: Valerie Hongoh, MSc, candidate au doctorat
Directeur: Pascal Michel, PhD (Université de Montréal)
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2016-05-16

Cette série de questions porte sur les maladies transmises par les moustiques (aussi appelés maringouins)

1. Selon vous, est-ce que tous les moustiques peuvent transmettre des maladies?
   - ☐ Oui
   - ☐ Non
   - ☐ Je ne sais pas / Je ne suis pas sûr

2. Selon vous, est-ce que les moustiques au Québec peuvent transmettre des maladies?
   - ☐ Oui
   - ☐ Non
   - ☐ Je ne sais pas / Je ne suis pas sûr

3. Êtes-vous inquiet au sujet du risque de contracter une maladie transmise par des moustiques au Québec?

Pas du tout (1)	2	3	4	5	6	7	8	9	Extrê-ment inquiet (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. Combien de contrôle personnel pensez-vous avoir sur le risque d'attraper une maladie transmise par un moustique?

Pas de contrôle du tout (1)	2	3	4	5	6	7	8	9	Contrôle complet (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. Quelle(s) maladie(s) parmi les suivantes peuvent-elles être transmises par des moustiques, sur la planète ? (Veuillez cocher toutes les cases qui s'appliquent selon vous)
   - ☐ SIDA
   - ☐ Chikungunya
   - ☐ Dengue
   - ☐ Malaria (Paludisme)
   - ☐ Encéphalite
   - ☐ Zika
   - ☐ Virus du Nil occidental
   - ☐ maladie de Lyme

6. Laquelle ou lesquelles des maladies suivantes peuvent-elles être transmises par des moustiques actuellement au Québec? (Veuillez cocher toutes les cases qui s'appliquent)
   - ☐ SIDA
   - ☐ Chikungunya
   - ☐ Dengue
   - ☐ Malaria (Paludisme)
   - ☐ Encéphalite
   - ☐ Zika
   - ☐ Virus du Nil occidental
   - ☐ Maladie de Lyme

7. Est-ce que vous voyez des moustiques pendant vos activités quotidiennes dans la saison estivale?
   ☐ Souvent / ☐ De temps en temps / ☐ Presque jamais / ☐ Jamais

8. À quelle fréquence êtes-vous piqué par des moustiques pendant la saison estivale?
☐ Souvent / ☐ De temps en temps / ☐ Presque jamais / ☐ Jamais

9. Quel impact ont les moustiques sur votre qualité de vie pendant la saison estivale?
☐ Nuisance / ☐ Risque pour ma santé / ☐ Aucun impact

10. Dans quels endroits êtes-vous piqués par des moustiques? (Veuillez cocher toutes les cases qui s'appliquent)
☐ À mon domicile / ☐ Lors de mes activités récréatives, en vacances / ☐ Au travail

11. Est-ce que vous éviteriez de voyager dans certains pays en raison de la préoccupation d'attraper une maladie transmise par un moustique? (Exemple: Zika)
☐ Oui / ☐ Non / ☐ Je ne sais pas

12. Pensez-vous que les moustiques sont un problème là où vous habitez?

Pas un problème du tout (1)	2	3	Problème important (4)
☐	☐	☐	☐

Durant l'été (ou lors des moments où les moustiques sont présents), utilisez-vous l'un des moyens suivants pour vous protéger contre les piqûres de moustiques?

		Jamais	**De temps en temps**	**La plupart du temps**	**Tou-jours**	**Je ne sais pas**
13.	« Je porte des vêtements longs de couleur claire pour aller à l'extérieur »	☐	☐	☐	☐	☐
14.	« J'utilise un produit chasse-moustiques sur ma peau lors de mes activités extérieures »	☐	☐	☐	☐	☐
15.	« J'utilise des produits chasse-moustiques contenant du DEET sur ma peau lors de mes activités extérieures »	☐	☐	☐	☐	☐
16.	« J'utilise des moustiquaires sur mes portes et fenêtres »	☐	☐	☐	☐	☐
17.	« J'inspecte les moustiquaires sur mes portes et fenêtres pour m'assurer qu'ils sont en bon état »	☐	☐	☐	☐	☐
18.	« Je vide l'eau stagnante dans les contenants extérieurs (*exemples : couvertures de piscine, pots de fleurs, bacs de recyclage, poubelles, etc.*) »	☐	☐	☐	☐	☐
19.	« Je change l'eau dans les bains d'oiseaux, bols d'animaux de compagnie réservoirs d'arrosage et autres autour de ma maison »	☐	☐	☐	☐	☐
20.	« J'utilise des pièges à insectes (bug zapper)»	☐	☐	☐	☐	☐
21.	« J'utilise des produits insecticides (chasse-moustiques) à l'extérieurs autour de ma maison ou de mon site de camping»	☐	☐	☐	☐	☐
22.	Autres moyens (inscrivez ici):					

Les énoncés suivants portent sur les comportements pour éviter les moustiques. Veuillez indiquer votre niveau d'accord en cliquant sur la case appropriée.

		Tout à fait en désaccord	**Plutôt en désaccord**	**Ni en accord ni en désaccord**	**Plutôt en accord**	**Tout à fait d'accord**
23.	«Il est difficile de se rappeler d'utiliser un produit insectifuge durant l'été »	☐	☐	☐	☐	☐
24.	«L'utilisation des produits chasse-moustiques est désagréable »	☐	☐	☐	☐	☐
25.	«L'utilisation des produits chasse-moustiques contenant	☐	☐	☐	☐	☐

	du DEET n'est pas sécuritaire pour ma santé vu leur toxicité »					
26.	«L'utilisation des produits chasse-moustiques contenant du DEET n'est pas sécuritaire pour l'environnement vu leur toxicité »	☐	☐	☐	☐	☐
27.	«Éviter les moustiques m'empêche de faire les choses que je veux faire »	☐	☐	☐	☐	☐
28.	«Les produits chasse-moustiques contenant du DEET sont chers (dispendieux) »	☐	☐	☐	☐	☐
29.	«Quand j'utilise des produits chasse-moustiques, je prends soin de moi»	☐	☐	☐	☐	☐
30.	«Quand j'utilise des produits chasse-moustiques, je m'inquiète moins à propos des maladies transmises par les moustiques »	☐	☐	☐	☐	☐
31.	«Quand j'évite les moustiques, je réduis mes chances d'attraper des maladies transmises par les moustiques»	☐	☐	☐	☐	☐
32.	«Quand j'évite les moustiques, je prends soin de moi»	☐	☐	☐	☐	☐
33.	«Quand j'utilise des produits chasse-moustiques, je réduis mes chances d'attraper une maladie transmise par un moustique»	☐	☐	☐	☐	☐

Cette prochaine série de questions porte sur le virus du Nil occidental

34. Avez-vous déjà entendu parler du virus du Nil occidental avant aujourd'hui ?
    - ☐ Oui
    - ☐ Non
    - ☐ Je ne sais pas

    Si non, sauter a la question #46

35. Selon vous, le virus du Nil occidental est transmis aux humains (cochez toutes les cases qui s'appliquent)
    - ☐ Lors d'un contact avec des animaux infectés
    - ☐ En serrant la main d'une personne infectée
    - ☐ Par la consommation d'eau ou d'aliments contaminés
    - ☐ Par la piqure d'une tique infectée
    - ☐ Par la piqure d'un moustique infecté
    - ☐ Je ne sais pas

[Nouvelle section : pas de recul à ce point]

Au Québec, la seule maladie transmise par les moustiques (aussi appelés maringouins) qui a donné lieu à des cas humains en 2015 était le virus du Nil occidental. Cette maladie est en circulation depuis 2002 dans la province de Québec, mais le risque de transmission à l'homme est extrêmement bas actuellement. L'an dernier, il y avait 45 cas signalés dans la province de Québec (sur une population de 8 millions).

36. Selon vous, quels sont les symptômes de l'infection au virus du Nil occidental chez l'humain (cochez toutes les cases qui s'appliquent)
    - ☐ Aucun symptôme
    - ☐ Des symptômes semblables à la grippe (*fièvre, maux de tête, courbatures)*
    - ☐ Diarrhée et vomissements
    - ☐ Rougeur sur la peau
    - ☐ Confusion, faiblesse musculaire et raideur de la nuque
    - ☐ Je ne sais pas
37. Selon vous, quel groupe d'individus est le plus vulnérable à l'infection causée par le virus du Nil occidental ? (cochez toutes les cases qui s'appliquent)

☐ Jeunes enfants
☐ Adultes plus âgés (50+)
☐ Tout le monde
☐ Je ne sais pas

38. *Selon vous, l'infection au virus du Nil occidental peut être traitée (cochez toutes les cases qui s'appliquent)*
☐ Avec des onguents sur la peau
☐ Avec des médicaments contre la grippe
☐ Soins hospitaliers de support dans certains cas
☐ Avec des antibiotiques
☐ Il n'y a actuellement aucun remède ou traitement
☐ Je ne sais pas

Pour chaque énoncé suivant, veuillez cocher la case appropriée.

		Tout à fait en désaccord	**Plutôt en dés-accord**	**Ni en désaccord ni en accord**	**Plutôt en accord**	**Tout à fait d'accord**
39.	« **Cet été** au Québec, si je **n'utilise PAS** des mesures préventives (*exemple : produits chasse-moustiques et port de vêtements long),* mon risque d'attraper le virus du Nil occidental est élevé »	☐	☐	☐	☐	☐
40.	«L'idée d'attraper le virus du Nil occidental me rend anxieux ou inquiet »	☐	☐	☐	☐	☐
41.	«Le virus du Nil occidental est une menace importante pour ma santé »	☐	☐	☐	☐	☐
42.	«C'est ma responsabilité de me protéger contre le virus du Nil occidental»	☐	☐	☐	☐	☐
43.	«C'est la responsabilité des autorités en santé publique de me protéger du virus du Nil occidental »	☐	☐	☐	☐	☐

[Nouvelle section : pas de recul à ce point]

Dans la majorité des cas, les personnes infectées par le Virus du Nil Occidental ne présentent aucun symptôme. Certaines personnes peuvent toutefois avoir des symptômes.

44. Pour la majorité des cas ayant des symptômes, sur une échelle de 1-10 (où 1=Pas d'effet, et 10=effets extrêmement graves), combien pensez-vous que le virus du Nil occidental affecte la qualité de vie des personnes qui sont infectées?

Pas d'effet (1)	2	3	4	5	6	7	8	9	Effets extrê-mement graves (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

45. Où obtenez-vous habituellement votre information liée à la santé et aux maladies (p.exe. à propos du virus du Nil occidental ou d'autres maladies transmises par les moustiques)
☐ Journaux
☐ Télévision
☐ Radio
☐ Panneaux d'affichage
☐ Internet (incluant les réseaux sociaux)
☐ Famille ou amis

☐ Docteurs, hôpitaux ou cliniques médicales

☐ Autre: Click here to enter text.

46. Avez-vous entendu parler du virus du Nil occidental l'été dernier (*exemple : radio, journaux, télévision, médias sociaux)*?

☐ Oui / ☐ Non / ☐ Je ne me souviens pas

47. Si oui, veuillez indiquer les sources de ces informations (cochez toutes les cases qui s'appliquent)

☐ Journaux
☐ Télévision
☐ Radio
☐ Panneaux d'affichage
☐ Internet (incluant les réseaux sociaux)
☐ Famille ou amis
☐ Docteurs, hôpitaux ou cliniques médicales
☐ Autre: Click here to enter text.
☐ Je ne me souviens pas

48. Concernant votre résidence personnelle, quel est l'énoncé qui décrit le mieux votre situation? (cochez toutes les cases qui s'appliquent)

☐ Je n'ai pas accès à un jardin ou terrasse extérieure ou balcon extérieur
☐ J'ai accès à un jardin ou terrasse extérieure, mais je n'ai pas la responsabilité de son entretien
☐ J'ai accès à un jardin ou terrasse extérieure et j'ai la responsabilité de son entretien
☐ J'ai accès à un balcon extérieur, mais je n'ai pas la responsabilité de son entretien
☐ J'ai accès à un balcon extérieur et j'ai la responsabilité de son entretien
☐ Autre: Click here to enter text.

49. Durant l'été, utilisez-vous un climatiseur?

☐ Oui, Climatiseur mural ou central (thermopompe)
☐ Oui, Climatiseur de fenêtre
☐ Oui, autre type de climatiseur
☐ Oui, un ventilateur (fan)
☐ Non, aucun climatiseur ni ventilateur

50. L'année dernière (entre mai et oct.), j'ai visité des zones boisées (*exemples: les parcs, les terrains de camping*):

☐ Pas du tout / ☐ Moins de 2 fois / ☐ 2 à 5 fois / ☐ 5 à 10 fois / ☐ Plus que 10 fois / ☐ Je ne me souviens pas

51. Connaissez-vous quelqu'un qui a déjà eu une maladie transmise par un moustique?

☐ Non / ☐ Oui / ☐ Je ne sais pas

52. Connaissez-vous quelqu'un qui a déjà eu le virus du Nil occidental?

☐ Non / ☐ Oui / ☐ Je ne sais pas

53. Lors des activités de prévention et de contrôle des maladies infectieuses comme le virus du Nil occidental, les autorités de santé publique doivent prendre en compte plusieurs enjeux et perspectives. Veuillez indiquer l'importance relative que vous attribuez aux enjeux suivants (Si possible, essayer de ne pas utiliser le même numéro deux fois):

		Le moins important 1	**2**	**3**	**4**	**5**	**Le plus important 6**
a.	«Protéger la santé des humains»	☐	☐	☐	☐	☐	☐
b.	«Protéger la santé de la faune»	☐	☐	☐	☐	☐	☐
c.	«Protéger la santé et la qualité de l'environnement et des	☐	☐	☐	☐	☐	☐

	écosystèmes »						
d.	« Respecter les intérêts et valeurs des citoyens »	☐	☐	☐	☐	☐	☐
e.	« Réduire les dépenses gouvernementales »	☐	☐	☐	☐	☐	☐
f.	« Mettre en places des mesures durables »	☐	☐	☐	☐	☐	☐

Cette série de questions porte sur le changement climatique

54. Selon vous, à propos des changements climatiques :
    - ☐ Les changements climatiques NE sont PAS en cours SAUTER À LA QUESTION #56
    - ☐ Les changements climatiques sont peut-être en cours, mais il n'y a pas de preuve scientifique SAUTER À LA QUESTION #56
    - ☐ Les changements climatiques sont en cours
    - ☐ Je ne sais pas

(SI RÉPONDU QUE LES CHANGEMENTS CLIMATIQUES SONT EN COURS)

55. Selon vous, le changement climatique est **principalement causé par** :
    - ☐ Les activités humaines
    - ☐ Des variations naturelles de la planète
    - ☐ On ne sait pas. Il n'y a pas de consensus scientifique
    - ☐ Un trou dans la couche d'ozone
    - ☐ Autre: Click here to enter text.
    - ☐ Je ne sais pas

56. Selon vous, le changement climatique peut entrainer les effets suivants (cochez tous ceux qui s'appliquent):
    - ☐ Inondations
    - ☐ Tremblement de terre
    - ☐ Risque de transmission de maladies infectieuses
    - ☐ Éruption volcanique
    - ☐ L'élévation du niveau de la mer
    - ☐ Les tsunamis
    - ☐ Aucun de ces effets
    - ☐ Je ne sais pas

Pour chacun des énoncés suivants, veuillez indiquer votre niveau d'accord en cliquant sur la case appropriée.

		Tout à fait en désaccord	**Plutôt en désaccord**	**Ni en accord ni en désaccord**	**Plutôt en accord**	**Tout à fait d'accord**
57.	«Les changements climatiques sont une menace pour ma santé»	☐	☐	☐	☐	☐
58.	«Je suis préoccupé par les changements climatiques »	☐	☐	☐	☐	☐
59.	«Les changements climatiques augmenteront le risque d'attraper certaines maladies infectieuses »	☐	☐	☐	☐	☐
60.	«C'est ma responsabilité de réduire mon empreinte carbone»	☐	☐	☐	☐	☐
61.	« Nous trouverons une solution technologique pour les changements climatiques »	☐	☐	☐	☐	☐

62. Pour chacune des énoncés suivants, indiquer la fréquence à laquelle vous avez participé à ces activités lors des 6 derniers mois :

		Jamais	**De temps en**	**La plupart du**	**Toujours**	**Je ne sais pas / ne s'applique**

			temps	temps		pas
a.	«J'ai réduit ma consommation d'électricité (*exemple : j'utilise des appareils éco énergétiques*) »	☐	☐	☐	☐	☐
b.	Si vous êtes propriétaire d'une voiture (sauf voitures électriques) : «je réduis mon utilisation de la voiture *(exemple : j'utilise le transport actif, en commun ou covoiturage)* »	☐	☐	☐	☐	☐
c.	«Je recycle ou je donne une deuxième vie à mes possessions (*exemple : dons de charité, échanges avec des amis ou vente de garage* »	☐	☐	☐	☐	☐
d.	«J'achète des produits locaux »	☐	☐	☐	☐	☐
e.	«Je réduis ma consommation de viande et de produits à base de viande»	☐	☐	☐	☐	☐

63. Pour chacun des énoncés suivants, veuillez indiquer le niveau de risque posé par l'énoncé pour la santé des Québécois :

		Risque majeur	Risque moyen	Risque mineur	Pas de risque	Je ne sais pas
a.	«Le changement climatique»	☐	☐	☐	☐	☐
b.	«Le virus du Nil occidental »	☐	☐	☐	☐	☐
c.	«Le virus Zika »	☐	☐	☐	☐	☐

64. Pour chacun des énoncés suivants, veuillez indiquer si le risque pour la santé des Québécois a augmenté, diminué ou est resté à peu près le même durant les 10 dernières années :

		Le risque a augmenté	Le risque a diminué	Le risque est resté à peu près le même	Je ne sais pas
a.	«Le changement climatique»	☐	☐	☐	☐
b.	«Le virus du Nil occidental »	☐	☐	☐	☐
c.	«Le virus Zika »	☐	☐	☐	☐

65. Selon vous, est-ce que les changements climatiques vont changer le risque des problèmes suivants au Québec: CC = Changement climatique

		Le CC augmentera absolument le risque	Le CC augmentera probablement le risque	Le CC n'augmentera probablement pas le risque	Le CC n'augmentera absolument pas le risque	Je ne sais pas
a.	«Les maladies transmises par les moustiques»	☐	☐	☐	☐	☐
b.	«Le virus du Nil occidental »	☐	☐	☐	☐	☐
c.	«Problèmes respiratoires»	☐	☐	☐	☐	☐
d.	«Coups de chaleur»	☐	☐	☐	☐	☐
e.	«Blessures liées aux temperatures froides»	☐	☐	☐	☐	☐

Ces dernières questions portent sur des informations sociodémographiques à des fins statistiques:

66. Vous êtes:

☐ Une femme / ☐ Un homme

67. Dans quelle catégorie d'âge vous situez-vous?

☐18-24 ans
☐25-34 ans
☐35-44 ans
☐45-54 ans

- ☐ 55-64 ans
- ☐ 65-74 ans
- ☐ 75 ans ou plus

68. Avez-vous des enfants de 18ans ou moins (qui habitent avec vous)?
    - ☐ Non
    - ☐ 1 enfant
    - ☐ 2 ou plus
69. Quel était le revenu total de votre ménage avant impôts l'année dernière?
    - ☐ 19,000$ ou moins
    - ☐ 20,000-39,000$
    - ☐ 40,000-59,000$
    - ☐ 60,000-79,000$
    - ☐ 80,000-99,000$
    - ☐ 100,000$ ou plus
    - ☐ Je préfère ne pas répondre
70. Quel est le niveau de scolarité le plus élevé que vous avez complété?
    - ☐ Primaire (7 ans ou moins)
    - ☐ Secondaire (8 à 12 ans)
    - ☐ Collégiale (DEC de formation préuniversitaire, de formation technique, ou certificats)
    - ☐ Universitaire : certificats et diplômes
    - ☐ Universitaire : 1er cycle Baccalauréat
    - ☐ Universitaire : 2e cycle Maîtrise
    - ☐ Universitaire : 3e cycle Doctorat
    - ☐ Autre: Click here to enter text.
71. Quelle est votre profession ou catégorie d'emploi actuelle?
    - ☐ Employé de bureau
    - ☐ Personnel spécialisé dans la vente (*exemples : vendeur, agent immobilier, représentant)*
    - ☐ Personnel spécialisé dans les services *(exemples : chauffeur de taxi, coiffeur, policier)*
    - ☐ Travailleur manuel (*exemple : agriculteur, travailleur forestier)*
    - ☐ Ouvrier spécialisé/semi-spécialisé (*exemples : chauffeur de camion, électricien, plombier)*
    - ☐ Travailleur des sciences et technologies (*exemples : informaticien, technicien de laboratoire)*
    - ☐ Professionnel (*exemples : architecte, biologiste,*)
    - ☐ Gestionnaire, administrateur ou propriétaire (*exemples : entrepreneur, politicien)*
    - ☐ Au foyer
    - ☐ Étudiant
    - ☐ Retraité
    - ☐ Sans emploi
    - ☐ Autre: Click here to enter text.

72. Quelle région habitez-vous (résidence principale)?
    - ☐ Montréal
    - ☐ Laval
    - ☐ Montérégie
    - ☐ Lanaudière
    - ☐ Laurentides
    - ☐ Autre: Click here to enter text.

Merci beaucoup d'avoir complété ce sondage.
Votre participation contribue à la production de connaissances scientifiques pour la santé publique.
Vos réponses demeureront strictement confidentielles.

Si vous voulez plus d'information sur le virus du Nil occidental,
nous vous invitons à consulter le site du gouvernement du Québec :
http://sante.gouv.qc.ca/problemes-de-sante/virus-du-nil/

Questionnaire (English)

"Adapting to the risk of climate sensitive infectious diseases"

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Supervisor: Pascal Michel, PhD (Université de Montréal)
Co-supervisor: Pierre Gosselin, MD MPH (U. Laval)

2016-05-16

The first set of questions pertains to Mosquito transmitted diseases

1. Do you think that all mosquitoes can transmit diseases?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure / I don't know

2. Do you think that mosquitoes in Quebec can transmit diseases?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure / I don't know

3. How worried are you about the risk of contracting a mosquito-transmitted disease in Quebec?

Not at all (1)	2	3	4	5	6	7	8	9	Extremely worried (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. How much personal control do you think you have over the risk of catching a mosquito -transmitted diseases?

No Control (1)	2	3	4	5	6	7	8	9	Extreme amount of control (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. Which of the following diseases can be transmitted by mosquitoes? (please check all that apply)
   - ☐ AIDS
   - ☐ Chikungunya
   - ☐ Dengue fever
   - ☐ Malaria
   - ☐ Encephalitis
   - ☐ Zika
   - ☐ West Nile
   - ☐ Lyme disease

6. Which of the following disease can be transmitted by mosquitoes in Quebec? (please check all that apply)
   - ☐ AIDS
   - ☐ Chikungunya
   - ☐ Dengue fever
   - ☐ Malaria
   - ☐ Encephalitis
   - ☐ Zika
   - ☐ West Nile
   - ☐ Lyme disease

7. Do you see mosquitoes during your daily activities in the summer season?
   - ☐ Often
   - ☐ Sometimes
   - ☐ Seldom
   - ☐ Never

8. How frequently are you bitten by mosquitoes during the summer season?
   - ☐ Often
   - ☐ Sometimes
   - ☐ Seldom
   - ☐ Never

9. What impact do mosquitoes have on your quality of life during the summer season? (Please check all that apply)
   ☐ Nuisance / ☐ Health risk / ☐ No concern

10. In which locations are you bitten by mosquitoes? (Please check all that apply)
    ☐ Home / ☐ Recreation / ☐ Work

11. Would you avoid travelling to certain countries because of concern of catching a mosquito-transmitted disease? *(example: Zika)*
    ☐ Yes / ☐ No / ☐ Don't know

12. How much of a problem do you think mosquitoes are where you live?

Not at problem (1)	2	3	Significant problem (4)
☐	☐	☐	☐

During the summer (or times when mosquitoes are present), do you use any of the following means to protect yourself from mosquito bites?

		Never	**Some-times**	**Usually**	**Always**	**Don't know**
	"Wear protective clothing such as long-sleeved shirts, long pants when outdoors"	☐	☐	☐	☐	☐
	"Use mosquito repellent on your skin when outdoors"	☐	☐	☐	☐	☐
	"Use mosquito repellent containing DEET on your skin when outdoors"	☐	☐	☐	☐	☐
	"Use screens on your doors and windows"	☐	☐	☐	☐	☐
	"Inspect screens on doors and windows to make sure they fit tightly and do not have holes"	☐	☐	☐	☐	☐
	"Drain standing water from outdoor containers around your home or cottage *(example: pool covers, flower pots, recycle bins, garbage cans, etc)*"	☐	☐	☐	☐	☐
	"Change water in outdoor containers around your home or cottage *(example: wading pools, bird baths, pet bowls and watering tanks, etc*)"	☐	☐	☐	☐	☐
	"Use bug zappers"	☐	☐	☐	☐	☐
	"Use outdoor insecticide bug sprays around your property or camp site"	☐	☐	☐	☐	☐
	Other: Click here to enter text.					

The following statements are about protective behaviours to avoid mosquitoes. Please indicate your level of agreement by clicking the appropriate box.

		Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
	"It is hard to remember to wear mosquito repellent in the	☐	☐	☐	☐	☐

	summer"					
	"Putting on mosquito repellent in the summer is unpleasant"	☐	☐	☐	☐	☐
	"Putting on mosquito repellent containing DEET is toxic to my health"	☐	☐	☐	☐	☐
	"Using mosquito repellent containing DEET is toxic to the environment"	☐	☐	☐	☐	☐
	"Avoiding mosquitoes keeps me from doing things I want to do"	☐	☐	☐	☐	☐
	"Bug repellent containing DEET is expensive"	☐	☐	☐	☐	☐
	"When I put on mosquito repellent, I am doing something to take care of myself"	☐	☐	☐	☐	☐
	"When I put on mosquito repellent, I don't worry as much about mosquito-transmitted diseases"	☐	☐	☐	☐	☐
	"Avoiding mosquitoes will decrease my chances of getting a mosquito-transmitted disease"	☐	☐	☐	☐	☐
	"When I avoid mosquitoes I am doing something to take care of myself"	☐	☐	☐	☐	☐
	"Putting on mosquito repellent will decrease my chances of getting a mosquito transmitted disease"	☐	☐	☐	☐	☐

The next set of questions pertain to West Nile virus

13. Before taking this survey, Had you ever heard of West Nile virus before?
    - ☐ Yes
    - ☐ No
    - ☐ I don't know

    If No, skip to question #46

14. To the best of your knowledge, how is West Nile virus transmitted to humans? (Please check all boxes that apply)
    - ☐ Contact with infected animals
    - ☐ Shaking hands with an infected person
    - ☐ Drinking contaminated water or food
    - ☐ The bite of an infected tick
    - ☐ The bite of an infected mosquito
    - ☐ I don't know

[New section : no going backwards to change previous answers after this point]

In Quebec, the only mosquito disease that resulted in human cases last year was West Nile virus. This disease has been in circulation since 2002 in the province of Quebec, but the risk of transmission to humans in extremely low presently. Last year there were 45 cases reported in the province of Quebec (out of a population of 8 million).

15. To the best of your knowledge, what signs or symptoms can West Nile virus cause in humans? (Please check all boxes that apply)
    - ☐ No symptoms
    - ☐ Flu-like symptoms such as fever, headaches or body aches
    - ☐ Diarrhea and vomiting
    - ☐ A bull's eye rash
    - ☐ Lack of coordination, muscle weakness and paralysis
    - ☐ I don't know

16. To the best of your knowledge, who is most vulnerable to West Nile virus? (Please check all boxes that apply)
    - ☐ Young children
    - ☐ Older adults (50+)
    - ☐ Everyone
    - ☐ I don't know

17. To the best of your knowledge, how is West Nile virus treated? (Please check all boxes that apply)
    - ☐ With topical ointments
    - ☐ Over the counter medication
    - ☐ Hospital care
    - ☐ With antibiotics
    - ☐ There is currently no cure or treatment
    - ☐ I don't know

For each statement below, please indicate your level of agreement by clicking the appropriate box.

		Strongly disagree	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
	"This summer in Quebec, if I do **NOT** use protective measures (*example*: *put on bug repellent and wear pants and long sleeves*), my chances of getting sick with West Nile are great"	☐	☐	☐	☐	☐
	"The thought of getting sick with West Nile virus makes me feel anxious or worried"	☐	☐	☐	☐	☐
	"West Nile virus is an important threat to my health"	☐	☐	☐	☐	☐
	"It is my responsibility to protect myself from West Nile virus"	☐	☐	☐	☐	☐
	"It is public health authorities' responsibility to protect me from West Nile virus"	☐	☐	☐	☐	☐

[New section : no going backwards to change previous answers after this point]

For the majority of cases, persons infected with West Nile virus have no symptoms. Some people can have symptoms.

18. For the majority of cases with symptoms, on a scale of 1-10 (where 1=no effect , and 10=severely affects), how much do you think West Nile virus affects the quality of life of people who are infected ?

No effect (1)	2	3	4	5	6	7	8	9	Severely affects (10)
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

19. Where do you usually get your information about health and diseases such as West Nile virus *(or other mosquito transmitted diseases)*?
    - ☐ Newspapers
    - ☐ TV
    - ☐ Radio
    - ☐ Billboards
    - ☐ Internet (including social media)
    - ☐ Family or friends
    - ☐ Doctors, hospitals or medical clinics
    - ☐ Other:

20. Do you remember seeing or hearing any information about West Nile virus last summer?

☐ Yes
☐ No
☐ Don't remember

21. If yes, please indicate which source (Please check all boxes that apply)
☐ Newspapers
☐ TV
☐ Radio
☐ Billboards
☐ Internet (including social media)
☐ Family or friends
☐ Doctors, hospitals or medical clinics
☐ Other: Click here to enter text.
☐ Don't remember

22. Which statement best describes your main residence?
☐ I do not have access to an outdoor garden or exterior terrace or balcony
☐ I have access to an outdoor garden or terrace, but I am not responsible for its upkeep
☐ I have access to an outdoor garden or terrace and I am responsible for its upkeep
☐ I have access to a balcony, but I am not responsible for its upkeep
☐ I have access to a balcony and I am responsible for its upkeep
☐ Other: Click here to enter text.

23. During the summer, do you use air conditioning or fans?
☐ Yes, central air conditioning (thermopump)
☐ Yes, window air conditioning unit
☐ Yes, other type of air conditioning unit
☐ Yes, an electric fan
☐ No, neither air conditioning nor fan

24. Last summer (between May and October), I visited wooded areas (*example: parks, camp grounds*):
☐ Not a single time
☐ Less than 2 times during the year
☐ Approximately 2 to 5 times during the year
☐ Approximately 5 to 10 times during the year
☐ More than 10 times during the year
☐ I don't remember

25. Do you know anyone who has ever been diagnosed with a mosquito-transmitted disease?
☐ No / ☐ Yes / ☐ Not sure

26. Do you know anyone who has ever been diagnosed with West Nile virus?
☐ No / ☐ Yes / ☐ Not sure

27. During prevention and control activities of infectious diseases such as West Nile virus, public health authorities often need to take many perspectives and considerations into account. Please indicate the importance you give to the following concerns by selecting a number from 1 to 6 for each concern listed below (If possible, try not to use the same number twice).

	Description of concern	**Least important 1**	**2**	**3**	**4**	**5**	**The most important 6**
a.	Protect the health of humans	☐	☐	☐	☐	☐	☐

b.	Protect the health of wildlife	☐	☐	☐	☐	☐	☐
c.	Protect the health and quality of the environment and ecosystems	☐	☐	☐	☐	☐	☐
d.	Respect the interest and values of citizens	☐	☐	☐	☐	☐	☐
e.	Reduce government spending	☐	☐	☐	☐	☐	☐
f.	Implement sustainable measures	☐	☐	☐	☐	☐	☐

This set of questions is about Climate change

28. To the best of your knowledge, on the subject of "climate change":

☐ Climate change is not currently taking place SKIP TO QUESTION #56

☐ Climate change may be taking place, but there is no scientific proof SKIP TO QUESTION #56

☐ Climate change is currently taking place

☐ I don't know

(If RESPONDED THAT CLIMATE CHANGE IS CURRENTLY TAKING PLACE)

29. To the best of your knowledge, what is **the primary cause** of "climate change"?

☐ Largely human activity

☐ A natural variation of the planet

☐ We don't know. There is no scientific consensus on the cause of global climate change.

☐ A hole in the ozone layer

☐ Other: _____

☐ I don't know

30. To the best of your knowledge, "climate change" can cause the following (Please check all boxes that apply):

☐ Flooding

☐ Earthquakes

☐ Risk of transmission of some infectious diseases (*example: Lyme disease)*

☐ Volcanic eruption

☐ Sea level rise

☐ Tsunamis

☐ None of the above

☐ I don't know

For each statement below, please indicate your level of agreement:

		Strongly disagree	**Disagree**	**Neither agree nor disagre**	**Agree**	**Strongly agree**
	"Climate change is a threat to my health"	☐	☐	☐	☐	☐
	"I am concerned about climate change"	☐	☐	☐	☐	☐
	"Climate change will increase the risk of getting sick with infectious diseases"	☐	☐	☐	☐	☐
	"It is my responsibility to reduce my carbon footprint"	☐	☐	☐	☐	☐
	"We will find a technological solution to climate change"	☐	☐	☐	☐	☐

31. For each statement below, please indicate how often you engaged in the activity within the last 6 months:

		Never	**Sometimes**	**Usually**	**Always**	**Don't know / Not applicable**
a.	"Reduced my electricity usage	☐	☐	☐	☐	☐

	(example: by using energy efficient appliances or light bulbs)"					
b.	If you own a car: "Reduced car use (*example: by using bicycles, public transportation or carpooling when possible)*"	☐	☐	☐	☐	☐
c.	"Recycled or repurposed items *(example: by donating to charity, exchanging with friends, or selling)*"	☐	☐	☐	☐	☐
d.	"Bought local products"	☐	☐	☐	☐	☐
e.	"Reduced consumption of meat and meat products"	☐	☐	☐	☐	☐

32. For each statement below, please indicate what you think the risk level is for Quebecers:
PLEASE USE A RANDOM ORDER FOR THE FOLLOWING STATEMENTS

		Major Risk	**Medium Risk**	**Minor Risk**	**No Risk**	**Don't know**
a.	"Climate change"	☐	☐	☐	☐	☐
b.	" West Nile virus"	☐	☐	☐	☐	☐
c.	"Zika virus"	☐	☐	☐	☐	☐

33. For each statement below, please indicate if you think that the risk to Quebecers has changed over the last 10 years:
PLEASE USE SAME ORDER AS PREVIOUS QUESTION

		Risk has increased	**Risk has stayed the same**	**Risk has decreased**	**Don't know**
a.	"Climate change"	☐	☐	☐	☐
b.	" West Nile virus"	☐	☐	☐	☐
c.	"Zika virus"	☐	☐	☐	☐

34. Do you think climate change will change the risk of the following in Quebec: CC=Climate Change

		CC will absolutely increase the risk	**CC will probably increase the risk**	**CC will probably decrease the risk**	**CC WILL absolutely decrease the risk**	**Don't know**
a.	"mosquito transmitted diseases"	☐	☐	☐	☐	☐
b.	" West Nile virus"	☐	☐	☐	☐	☐
c.	"respiratory problems"	☐	☐	☐	☐	☐
d.	"heat stroke"	☐	☐	☐	☐	☐
e.	"cold weather related injuries"	☐	☐	☐	☐	☐

The last set of questions is socio-demographic information for statistical purposes:

35. What is your gender:
☐Female / ☐Male

36. What is your age?
☐18-24 years old
☐25-34 years old
☐35-44 years old
☐45-54 years old
☐55-64 years old

☐ 65-74 years old
☐ 75 years or older

37. Do you have children less than 18 years of age?
    ☐ No
    ☐ 1 child
    ☐ 2 or more

38. What was the total income of your household before taxes last year?
    ☐ $19,000 or less
    ☐ 20,000-39,000$
    ☐ 40,000-59,000$
    ☐ 60,000-79,000$
    ☐ 80,000-99,000$
    ☐ 100,000$ or more
    ☐ I prefer not to answer

39. What is the highest degree or level of school you have completed?
    ☐ Primary school (7 years or less)
    ☐ High school (8 to 12 years)
    ☐ College (Pre-university diploma, technical diploma or certificate)
    ☐ University certificates and/or diplomas
    ☐ Bachelor's degree
    ☐ Master's degree
    ☐ Doctorate degree
    ☐ Other: Click here to enter text.

40. What is your main occupation (*work)*?
    ☐ Office worker
    ☐ Sales specialist (*example: sales agent, real estate agent)*
    ☐ Services specialist (*example: taxi driver, hairdresser, police officer)*
    ☐ Manual worker (*example: farmer, forestry worker*)
    ☐ Skilled or semi-skilled worker (*example: truck driver, electrician, and plumber)*
    ☐ Science and technology specialist
    (*Example: computer specialist, laboratory technician*)
    ☐ Professional (*example: architect, biologist,*)
    ☐ Manager, administrator (*example: entrepreneur, politician)*
    ☐ Homemaker
    ☐ Student
    ☐ Retired
    ☐ Unemployed
    ☐ Other: Click here to enter text.

41. In which region do you live (primary residence)?
    ☐ Montreal
    ☐ Laval
    ☐ Montérégie
    ☐ Lanaudière
    ☐ Laurentians
    ☐ Other: Click here to enter text.

Thank you very much for completing this survey.
Your participation is contributing to generating scientific knowledge for public health.
Your answers will be kept strictly confidential.

If you would like more information on West Nile virus,
We invite you to consult the Quebec government website:
http://sante.gouv.qc.ca/en/problemes-de-sante/virus-du-nil/

APPENDIX 4: SUPPORTING INFORMATION FOR CHAPTER 5

Assessing effective interventions to manage west nile virus using multi-criteria decision analysis with climate change scenarios

Valerie Hongoh, Céline Campagna, Mirna Panic, Onil Samuel, Pierre Gosselin, Jean-Philippe Wauub, André Ravel, Karim Samoura, Pascal Michel

List of Supplementary Materials:

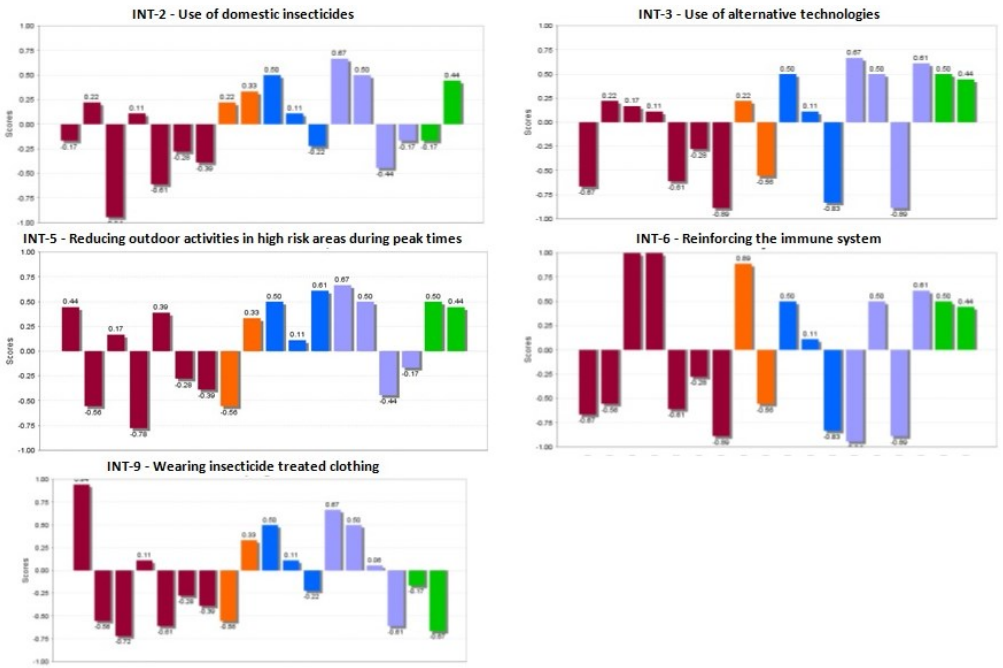

Figure 15. Additional individual-level protection strategy performance profiles.

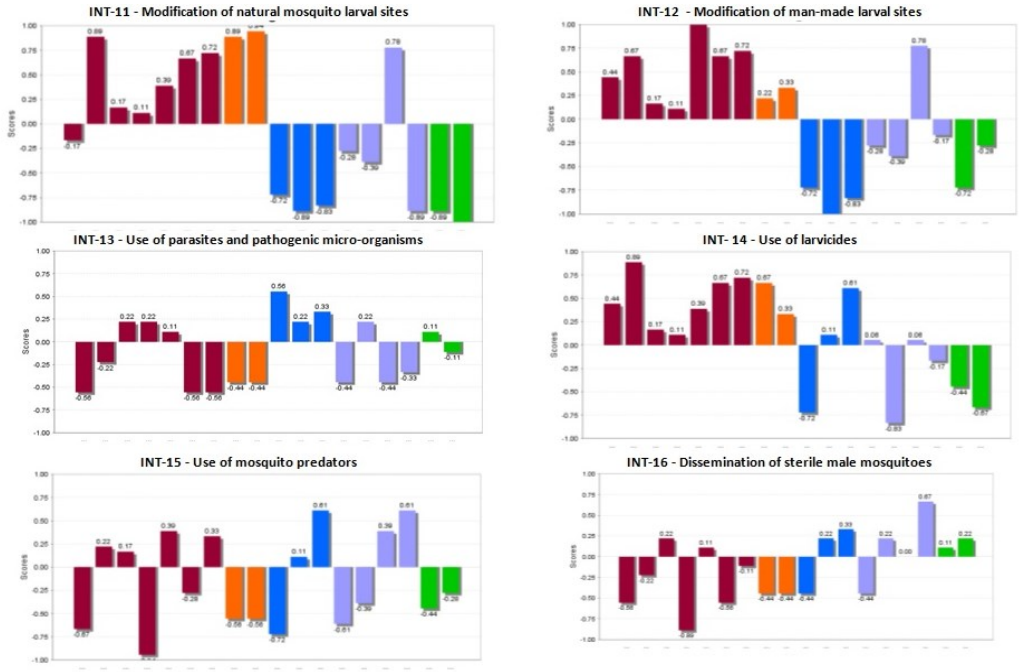

Figure 16. Regional-level management intervention profiles (interventions 11-16).

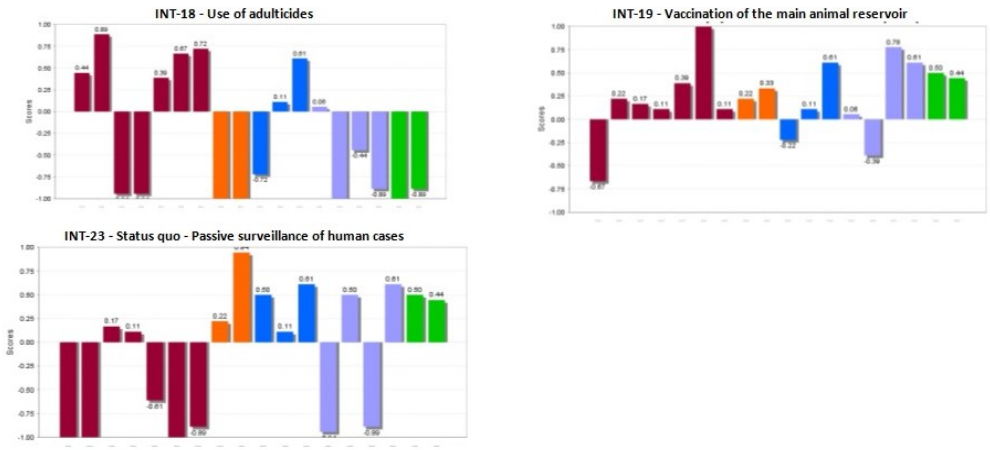

Figure 17. Regional-level management intervention profiles (interventions 18-23).

Table XLIII. Measurement scales used to score interventions in the model

Category	WNV criteria	Description	Measurement scale	
Public Health Criteria (PHC)				
	PHC1 - Incidence reduction	Reduction in incidence of human cases (or case proportion in population)	-1 : increase in cases 0: no difference 1: small reduction 2: moderate reduction 3: high reduction 4: significant reduction	
	PHC2 - Entomological risk reduction	Reduction of entomological risk (infection rate or abundance of main vectors)	-1 : increased risk 0: no difference 1: small reduction 2: moderate reduction 3: high reduction 4: significant reduction	
	PHC3 –Physical health impact	Impacts to human physical health (including susceptible populations) = Intensity * Duration of Effect	Intensity: • -4 : significant beneficial effect • -3 : high beneficial effect • -2: moderate beneficial effect • -1: minimal beneficial effect • 0: no effect • 1: minimal adverse and reversible effect • 2: moderate adverse effect • 3: high adverse effect • 4: significant adverse effect	Duration of effect : • 1: short -term effect, reversible • 2 short-term effect, reversible • 3: sub- chronic effect, reversible • 4: chronic effect, irreversible
	PHC4 - Mental health impact	Impacts to human mental and psychosocial health (including susceptible populations) = Intensity * Duration of Effect	Intensity: • -4 : significant beneficial effect • -3 : High beneficial effect • -2: moderate beneficial effect • -1: minimal beneficial effect • 0: no effect • 1: minimal adverse and reversible effect • 2: moderate adverse effect • 3: high adverse effect • 4: significant adverse effect	Duration of effect : • 1: short -term effect, reversible • 2 short-term effect, reversible • 3: sub- chronic effect, reversible • 4: chronic effect, irreversible
	PHC5 – Social equity	Impact on social equity	• -2: very positive effect • -1: rather positive effect • 0: no effect • 1: rather negative effect • 2: very negative effect	
	PHC6 – Reduction of circulating virus	Reduction in level of circulating virus in animal reservoir (infection rate or density of population)	• 1: increase • 0: no difference • 1: small reduction • 2: moderate reduction • 3: High reduction • 4: significant reduction	

Category	WNV criteria	Description	Measurement scale
	PHC7 – Proportion affected	Proportion of population that benefits from the action	• 0: no individual • 1: low proportion of affected individuals (<25%) • 2 : moderate proportion (25-50%) • 3: significant proportion (50-75%) • 4 : majority of the population (> 75%)
Social Impact Criteria (SIC)			
	SIC1 – Public acceptance	Level of public acceptance (agreement or non-agreement of the intervention by the population or stakeholders)	• -2: major disagreement • -1: low disagreement • 0: no effect • 1: low agreement • 2: important agreement
	SIC2 – Impact to credibility	Impact to confidence in and credibility of organisation in charge (including adhesion to key messages)	• -3: significant increase in degree of confidence • -2: moderate increase in degree of confidence • -1: slight increase in degree of confidence • 0: no effect • 1: small reduction in degree of confidence • 2: moderate reduction in degree of confidence • 3: significant reduction in degree of confidence
Economic Criteria (ECC)			
	ECC1 – Government cost	Cost to the government (national or province/state)	• 0: no cost • 1: minimal costs (a few thousand) • 2: moderate costs (hundreds of thousands) • 3: high costs (millions)
	ECC2 – Municipal cost	Cost to municipalities	• 0: no cost • 1: minimal costs (a few thousand) • 2: moderate costs (hundreds of thousands) • 3: high costs (millions)
	ECC3 – Individual cost	Cost to individuals and private sector	0 : no cost 1 : minimal costs (individual <30$, private <100$) 2 : moderate costs (individual 31-100$; private <100$) 3 : high costs (individual >100$; private > 1000$)
Strategic & Operational Criteria (SOC)			
	SOC1 - Delay	Delay before appearance of desired effect	• 0: no delay • 1: very short term • 2: short term • 3 : medium • 4: long term • 5 : very long term
	SOC2 – Complexity	Institutional and operational complexity of the action (including structural changes, hiring, etc.)	• 1: Simple (minor institutional changes) • 2: Intermediate (requires hiring and further planning) • 3: moderate (requires new working teams in a sector of intervention) • 4: Complex (requires inter-sectoral / inter-institutional changes) • 5: Very complex (requires the creation of new structures or organizations)

Category	WNV criteria	Description	Measurement scale	
	SOC3 – Sustainability	Sustainability of the action (or efficacy in time)	• 0: no duration • 1: in days • 2: in weeks • 3: in months • 4: in years	
	SOC4 – Other policy impact	Impact on other public policies (including potential conflicts with recommendations, economic efforts, etc.)	• -1: concordance / synergy • 0: no conflict • 1: low conflict • 2: moderate conflicts • 3: major conflicts	
Animal & Environmental Criteria (AEC)				
	AEC1 – Animal health impact	Impact on animal health and biodiversity = Type of effect * Scope * Value of species	Type of effect : • -1: health Improvement • 0: no effect • 1: morbidity • 2 : mortality Scope (number of species affected) : • 1: no species • 2: some species • 3: several species	Value of affected species (economic/ecological value, or endangered status) : • 1: low-value species or not at risk • 2: species of low values or susceptible species • 3: moderate value or vulnerable/of concern species • 4: important value of species or threatened/ endangered
	AEC2 – Environmental impact	Impact on physical environment and ecosystems = Type of effect * Scope * Value	Type of effect : • -1: improvement • 0: no effect • 1: low effect • 2: moderate effects • 3: High effects Geographic scope: • 1: none • 2: small scale • 3 large scale;	Value : • 1: none • 2 : terrestrial environment • 3 : aquatic environment • 4: terrestrial and aquatic environments • 5: complex ecosystems (water – air - ground)

Table XLIV. Matrix of evaluation scores for the interventions in the Quebec WNV management model

Criteria / Intervention	PHC-01	PHC-02	PHC-03	PHC-04	PHC-05	PHC-06	PHC-07	SIC-01	SIC-02	ECC-01	ECC-02	ECC-03	SOC-01	SOC-02	SOC-03	SOC-04	AEC-01	AEC-02
INT-1	2	0	2	0	1	0	1	-1	0	0	0	1	0	0	1	0	0	0
INT-2	1	1	4	0	1	0	1	0	0	0	0	1	0	0	1	1	1	0
INT-3	0	1	0	0	1	0	0	0	1	0	0	2	0	0	0	0	0	0
INT-4	2	0	-1	0	0	0	1	0	0	0	0	1	0	0	1	1	0	0
INT-5	2	0	0	1	0	0	1	-1	0	0	0	0	0	0	1	1	0	0
INT-6	0	0	-9	-9	1	0	0	2	1	0	0	2	5	0	0	0	0	0
INT-7	3	0	0	0	1	0	4	2	1	0	0	1	0	0	4	0	0	0
INT-8	2	0	1	0	1	0	2	-1	1	3	0	1	3	3	4	0	0	0
INT-9	3	0	2	0	1	0	1	-1	0	0	0	1	0	0	2	2	1	6
INT-10	1	1	0	0	0	0	1	0	0	0	0	1	1	0	2	1	0	0
INT-11	1	3	0	0	0	1	4	2	-2	3	2	2	2	2	4	3	6	12
INT-12	2	2	0	0	-1	1	4	0	0	3	3	2	2	2	4	1	4	2
INT-13	0	1	0	0	0	0	2	-1	1	2	0	0	3	2	2	2	2	4
INT-14	2	3	0	0	0	1	4	1	0	3	0	0	1	3	2	1	2	6
INT-15	1	1	0	0	0	1	4	-1	1	2	0	0	3	2	3	3	4	6
INT-16	0	1	0	2	0	0	3	-1	1	3	0	0	3	2	3	0	2	2
INT-18	2	3	4	2	0	1	4	-2	2	3	0	0	1	4	1	3	12	8
INT-19	0	1	0	0	0	4	2	0	0	2	0	0	1	2	4	0	0	0
INT-23	-1	-1	0	0	1	-1	0	0	-2	0	0	0	5	0	0	0	0	0

PHC: Public health Criteria, SIC: Social impact criteria, ECC: economic criteria, SOC: strategic and operational criteria, AEC: animal and environmental health criteria.

Table XLV. Stakeholder weighting results by criteria and category for the Scenarios 1& 2 (low risk transmission)

Scenario 1	**S1**		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**		**S8**		**S9**		**S10**		**S11**		**S12**	
PHC-01	16		10		9		5		11		15		16		6.25		6.67		16		16.8		0	
PHC-02	8		10		3		5		11		0		8		5		6.67		6		4.8		0	
PHC-03	4		5		3		5		3		20		6		7.5		6.67		10		2.4		25	
PHC-04	4	40	5	50	3	30	5	50	3	50	10	50	2	40	1.25	25	6.67	66.69	2	40	0.96	48	20	55
PHC-05	2		5		3		5		1		2.5		4		1.25		6.67		2		2.4		5	
PHC-06	2		5		3		5		1		0		0		1.875		6.67		2		4.8		0	
PHC-07	4		10		6		20		20		2.5		4		1.875		26.67		2		15.84		5	
SIC-01	2	5	5	10	7	10	5	10	2.5	5	5	10	10	10	6.4	8	0	0	5	10	3	10	5	10
SIC-02	3		5		3		5		2.5		5		0		1.6		0		5		7		5	
ECC-01	7.5		7.5		5		6.25		6.8		6.25		7.5		44		8.33		10		8		25	
ECC-02	2.5	25	5.25	15	5	20	6.25	25	6.6	20	6.25	25	3.75	15	8.25	55	8.33	33.33	7.5	25	7	20	0	25
ECC-03	15		2.25		10		12.5		6.6		12.5		3.75		2.75		16.67		7.5		5		0	
SOC-01	6		4		5.25		0		7.5		2.5		5		3		0		0.5		5		2	
SOC-02	4	20	7	20	2.25	15	7.5	15	3.75	15	2.5	10	7.5	25	3	10	0	0	1	5	4	20	2	8
SOC-03	8		7		6		7.5		1.95		2.5		5		2.5		0		3		5		2	
SOC-04	2		2		1.5		0		1.8		2.5		7.5		1.5		0		0.5		6		2	
AEC-01	5	10	2.5	5	10	25	0	0	5	10	2.5	5	5	10	0.8	2	0	0	10	20	1.2	2	1	2
AEC-02	5		2.5		15		0		5		2.5		5		1.2		0		10		0.8		1	
Scenario 2	**S1**		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**		**S8**		**S9**		**S10**		**S11**		**S12**	
PHC-01	16		10		9		12		11		15		16		14		0		8.75		16.96		0	
PHC-02	8		10		3		12		11		0		8		6		0		5		5.3		0	
PHC-03	4		5		3		0		3		20		4		4		8		7.5		2.65		25	
PHC-04	4	40	5	50	3	30	6	30	3	50	10	50	4	40	2	40	2	10	2	25	2.65	53	20	55
PHC-05	2		5		3		0		1		2.5		4		2		0		0.5		2.65		5	
PHC-06	2		5		3		0		1		0		0		6		0		0.5		2.65		0	
PHC-07	4		10		6		0		20		2.5		4		6		0		0.75		20.14		5	
SIC-01	2	5	5	10	7	10	10	20	2.5	5	5	10	5	10	8	10	0	0	2	10	5.25	15	5	10
SIC-02	3		5		3		10		2.5		5		5		2		0		8		9.75		5	
ECC-01	7.5		7.5		5		0		6.8		6.25		10		32		40		10		1.75		25	
ECC-02	2.5	25	5.25	15	5	20	5	10	6.6	20	6.25	25	5	20	6	40	40	80	7.5	25	1.75	5	0	25
ECC-03	15		2.25		10		5		6.6		12.5		5		2		0		7.5		1.5		0	
SOC-01	6		4		5.25		9		7.5		2.5		5		2.4		0		6		6.25		2	
SOC-02	4	20	7	20	2.25	15	9	30	3.75	15	2.5	10	5	20	2.4	8	0	0	6	20	7.5	25	2	8
SOC-03	8		7		6		12		1.95		2.5		5		2		0		6		5		2	
SOC-04	2		2		1.5		0		1.8		2.5		5		1.2		0		2		6.25		2	
AEC-01	5	10	2.5	5	10	25	3	10	5	10	2.5	5	5	10	0.8	2	1	10	10	20	1.2	2	1	2
AEC-02	5		2.5		15		7		5		2.5		5		1.2		9		10		0.8		1	

PHC: Public health Criteria, SIC: Social impact criteria, ECC: economic criteria, SOC: strategic and operational criteria, AEC: animal and environmental health criteria. S1-S12 – stakeholders 1-12.

Table XLVI. Stakeholder weighting results by criteria and category for the Scenarios 3& 4 (medium risk transmission)

Scenario 3	**S1**		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**		**S8**		**S9**		**S10**		**S11**		**S12**	
PHC-01	16		15		10.5		12		11		22		55		10		0		5		17.5		20	
PHC-02	8		10		3.5		6		11		0		12		12.5		0		3.75		10		0	
PHC-03	4		5		3.5		6		3		16		4		12.5		40		7.5		2.5		15	
PHC-04	4	40	5	50	3.5	35	6	30	3	50	6	50	2	40	5	50	10	50	1.25	25	1	50	5	45
PHC-05	2		5		3.5		0		1		3		2		2.5		0		2.5		1.5		5	
PHC-06	2		0		3.5		0		1		0		0		2.5		0		2.5		2.5		0	
PHC-07	4		10		7		0		20		3		2		5		0		2.5		15		0	
SIC-01	2	5	2.5	5	7	10	10	20	2.5	5	7	25	10	15	8	10	0	0	12	30	2	10	10	25
SIC-02	3		2.5		3		10		2.5		18		7.5		2		0		18		8		15	
ECC-01	7.5		5		2.5		0		3.4		25		25		15		10		12.5		6		20	
ECC-02	2.5	25	3.5	10	2.5	10	5	10	3.3	10	0	25	3.5	10	3	20	10	20	7.5	25	7	20	0	20
ECC-03	15		1.5		5		5		3.3		0		3		2		0		5		7		0	
SOC-01	6		6		10.5		9		24		0		8		6		1		1.5		10.8		10	
SOC-02	4	20	10.5	30	4.5	30	9	30	4.5	30	0	0	10.5	30	3	15	6	10	1.25	5	1.8	18	0	10
SOC-03	8		10.5		12		12		0.9		0		6		6		1		1.75		2.7		0	
SOC-04	2		3		3		0		0.6		0		1.5		0		2		0.5		2.7		0	
AEC-01	5	10	2.5	5	6	15	5	10	2.5	5	0	0	2	5	2.5	5	6	20	6	15	1.5	2	0	0
AEC-02	5		2.5		9		5		2.5		0		2.5		2.5		14		9		0.5		0	
Scenario 4	**S1**		**S2**		**S3**		**S4**		**S5**		**S6**		**S7**		**S8**		**S9**		**S10**		**S11**		**S12**	
PHC-01	16		15		10.5		12		12		22		55		12.5		0		4		16.5		20	
PHC-02	8		10		3.5		6		12		0		10		10		0		3		11		0	
PHC-03	4		5		3.5		6		3		16		6		12.5		48		6		2.75		15	
PHC-04	4	40	5	50	3.5	35	6	30	3	50	6	50	4	40	4	50	12	60	1	20	1.1	55	5	45
PHC-05	2		5		3.5		0		0		3		2		1		0		2		1.65		5	
PHC-06	2		0		3.5		0		0		0		0		5		0		2		2.75		0	
PHC-07	4		10		7		0		20		3		4		5		0		2		19.25		0	
SIC-01	2	5	2.5	5	7	10	10	20	2.5	5	7	25	10	15	17	20	0	0	8	20	3	15	10	25
SIC-02	3		2.5		3		10		2.5		18		7.5		3		0		12		12		15	
ECC-01	7.5		5		3.75		0		3.4		25		25		15		10		12.5		1.5		20	
ECC-02	2.5	25	3.5	10	3.75	15	5	10	3.3	10	0	25	5.25	15	3	20	10	20	7.5	25	1.75	5	0	20
ECC-03	15		1.5		7.5		5		3.3		0		4.5		2		0		5		1.75		0	
SOC-01	6		6		7		9		24		0		8		3.2		2.222		6		17.25		10	
SOC-02	4	20	10.5	30	3	20	9	30	4.5	30	0	0	7	20	1.6	8	2.78	10	5	20	2.3	23	0	10
SOC-03	8		10.5		8		12		0.9		0		4		3.2		2.778		7		1.15		0	
SOC-04	2		3		2		0		0.6		0		1		0		2.222		2		2.3		0	
AEC-01	5	10	2.5	5	8	20	5	10	2.5	5	0	0	2	10	1	2	4	10	6	15	1.5	2	0	0
AEC-02	5		2.5		12		5		2.5		0		5		1		6		9		0.5		0	

PHC: Public health Criteria, SIC: Social impact criteria, ECC: economic criteria, SOC: strategic and operational criteria, AEC: animal and environmental health criteria. S1-S12 – stakeholders 1-12.

Table XLVII. Stakeholder weighting results by criteria and category for the Scenarios 5& 6 (high risk transmission)

Scenario 5	S1		S2		S3		S4		S5		S6		S7		S8		S9		S10		S11		S12	
PHC-01	16		10		15		8		11		63		14		18		13		6		17.6		40	
PHC-02	8		10		7.5		0		11		0		8		15		0		4.5		11		0	
PHC-03	4		5		5		8		3		27		8		21		35.75		9		2.75		20	
PHC-04	4	40	5	50	5	50	8	40	3	50	0	90	4	40	0	60	16.25	65	3	30	1.1	55	0	60
PHC-05	2		5		5		0		1		0		2		0		0		1.5		1.65		0	
PHC-06	2		5		7.5		8		1		0		2		3		0		3		5.5		0	
PHC-07	4		10		5		8		20		0		2		3		0		3		15.4		0	
SIC-01	2	5	5	10	3.5	5	15	30	2.5	5	2.5	5	10	20	1.4	2	12.5	25	12.5	25	1.75	5	0	20
SIC-02	3		5		1.5		15		2.5		2.5		10		0.6		12.5		12.5		3.25		20	
ECC-01	7.5		5		2.5		4		6.8		5		10		27		0		10		8		5	
ECC-02	2.5	25	3.5	10	2.5	10	4	10	6.6	20	0	5	5	20	3	30	0	0	6	20	7	20	0	5
ECC-03	15		1.5		5		2		6.6		0		5		0		0		4		5		0	
SOC-01	6		5		8.75		0		7.5		0		1.5		1.5		0		1.5		6		15	
SOC-02	4	20	8.75	25	3.75	25	5	10	3.75	15	0	0	6	15	3.6	6	0	0	1.25	5	2.25	15	0	15
SOC-03	8		8.75		10		5		1.95		0		6		0.9		0		1.75		2.25		0	
SOC-04	2		2.5		2.5		0		1.8		0		1.5		0		0		0.5		4.5		0	
AEC-01	5	10	2.5	5	4	10	5	10	5	10	0	0	2.5	5	0.8	2	3	10	8	20	2.5	5	0	0
AEC-02	5		2.5		6		5		5		0		2.5		1.2		7		12		2.5		0	
Scenario 6	S1		S2		S3		S4		S5		S6		S7		S8		S9		S10		S11		S12	
PHC-01	16		10		15		8		11		16		14		24		13		5		15.4		40	
PHC-02	8		10		7.5		0		11		0		8		24		0		3.75		11		0	
PHC-03	4		5		5		8		3		8		8		28		35.75		7.5		2.75		20	
PHC-04	4	40	5	50	5	50	8	40	3	50	8	40	4	40	0	80	16.25	65	1.25	25	1.1	55	0	60
PHC-05	2		5		5		0		1		4		2		0		0		2.5		1.65		0	
PHC-06	2		5		7.5		8		1		0		2		2.4		0		2.5		5.5		0	
PHC-07	4		10		5		8		20		4		2		1.6		0		2.5		17.6		0	
SIC-01	2	5	5	10	3.5	5	10	20	2.5	5	5	10	10	20	0.7	1	12.5	25	8	20	5.25	15	0	20
SIC-02	3		5		1.5		10		2.5		5		10		0.3		12.5		12		9.75		20	
ECC-01	7.5		5		2.5		8		6.8		30		7.5		13.5		0		15		2		5	
ECC-02	2.5	25	3.5	10	2.5	10	8	20	6.6	20	0	30	3.75	15	1.5	15	0	0	7.5	25	1.75	5	0	5
ECC-03	15		1.5		5		4		6.6		0		3.75		0		0		2.5		1.25		0	
SOC-01	6		5		8.75		0		7.5		2.5		1.5		0.6		0		6		8		15	
SOC-02	4	20	8.75	25	3.75	25	5	10	3.75	15	2.5	10	4.5	15	1.8	3	0	0	5	20	3	20	0	15
SOC-03	8		8.75		10		5		1.95		2.5		7.5		0.6		0		7		3		0	
SOC-04	2		2.5		2.5		0		1.8		2.5		1.5		0		0		2		6		0	
AEC-01	5	10	2.5	5	4	10	5	10	5	10	5	10	5	10	0.4	1	3	10	5	10	2.5	5	0	0
AEC-02	5		2.5		6		5		5		5		5		0.6		7		5		2.5		0	

PHC: Public health Criteria, SIC: Social impact criteria, ECC: economic criteria, SOC: strategic and operational criteria, AEC: animal and environmental health criteria. S1-S12 – stakeholders 1-12.

SR3 - References used in the assessment of management interventions

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APPENDIX 5: SUPPORTING INFORMATION FOR CHAPTER 6

Can malaria management be improved using a participatory multi-stakeholder decision aid approach with local stakeholders

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List of Supplementary Materials:

Table XLVIII. Measurement scales used to score interventions in the model.
SR4 - References used in the assessment of management interventions.

Table XLVIII. Measurement scales used to score interventions in the model.

Category	WNV criteria	Description	Measurement scale	
Public Health Criteria (PHC)				
	PHC1 - Incidence reduction	Reduction in incidence of human cases (or case proportion in population)	-1 : increase in cases 0: no difference 1: small reduction (0-25%) 2: moderate reduction (26-50%) 3: high reduction (51-75%) 4: significant reduction (75+%)	
	PHC2 - Entomological risk reduction	Reduction of entomological risk (infection rate or abundance of main vectors)	-1 : increased risk 0: no difference 1: small reduction 2: moderate reduction 3: high reduction 4: significant reduction	
	PHC3 –Differential Diagnostic		0: Does not contribute 1: Contributes to differential diagnostic	
	PHC4 –Physical health impact	Impacts to human physical health (including susceptible populations) = Intensity * Duration of Effect	Intensity: • -4 : significant beneficial effect • -3 : high beneficial effect • -2: moderate beneficial effect • -1: minimal beneficial effect • 0: no effect • 1: minimal adverse and reversible effect • 2: moderate adverse effect • 3: high adverse effect • 4: significant adverse effect	Duration of effect : • 1: short -term effect, reversible • 2 short-term effect, reversible • 3: sub- chronic effect, reversible • 4: chronic effect, irreversible
	PHC5 - Mental health impact	Impacts to human mental and psychosocial health (including susceptible populations) = Intensity * Duration of Effect	Intensity: • -4 : significant beneficial effect • -3 : High beneficial effect • -2: moderate beneficial effect • -1: minimal beneficial effect • 0: no effect • 1: minimal adverse and reversible effect • 2: moderate adverse effect • 3: high adverse effect • 4: significant adverse effect	Duration of effect : • 1: short -term effect, reversible • 2 short-term effect, reversible • 3: sub- chronic effect, reversible • 4: chronic effect, irreversible
	PHC6 – Social equity	Impact on social equity	• -1: positive effect • 0: no effect • 1: negative effect	

Category	WNV criteria	Description	Measurement scale
	PHC7 – Proportion affected	Proportion of population that benefits from the action	• 0: no individual • 1: low proportion of affected individuals (<25%) • 2 : moderate proportion (25-50%) • 3: significant proportion (50-75%) • 4 : majority of the population (> 75%)
Social Impact Criteria (SIC)			
	SIC1 – Public acceptance	Level of public acceptance (agreement or non-agreement of the intervention by the population or stakeholders)	• -2: major disagreement • -1: low disagreement • 0: no effect • 1: low agreement • 2: important agreement
	SIC2 – Impact to credibility	Impact to confidence in and credibility of organisation in charge (including adhesion to key messages)	• -3: significant increase in degree of confidence • -2: moderate increase in degree of confidence • -1: slight increase in degree of confidence • 0: no effect • 1: small reduction in degree of confidence • 2: moderate reduction in degree of confidence • 3: significant reduction in degree of confidence
Economic Criteria (ECC)			
	ECC1 – Government cost	Cost to the government (national or province/state)	• 0: no cost • 1: minimal costs (a few thousand) • 2: moderate costs (hundreds of thousands) • 3: high costs (millions)
	ECC2 – Municipal cost	Cost to municipalities	• 0: no cost • 1: minimal costs (a few thousand) • 2: moderate costs (hundreds of thousands) • 3: high costs (millions)
	ECC3 – Individual cost	Cost to individuals and private sector	0 : no cost 1 : minimal costs (individual <30$, private <100$) 2 : moderate costs (individual 31-100$; private <100$) 3 : high costs (individual >100$; private > 1000$)
Strategic & Operational Criteria (SOC)			
	SOC1 - Delay	Delay before appearance of desired effect	• 0: no delay • 1: very short term • 2: short term • 3 : medium • 4: long term • 5 : very long term

Category	WNV criteria	Description	Measurement scale	
	SOC2 – Complexity	Institutional and operational complexity of the action (including structural changes, hiring, etc.)	• 1: Simple (minor institutional changes) • 2: Intermediate (requires hiring and further planning) • 3: moderate (requires new working teams in a sector of intervention) • 4: Complex (requires inter-sectoral / inter-institutional changes) • 5: Very complex (requires the creation of new structures or organizations)	
	SOC3 – Sustainability	Sustainability of the action (or efficacy in time)	• 1: weak sustainability, financing for 1 time • 2: medium sustainability, financing available for multiple applications; • 3: high sustainability – inexpensive measure, easily accessible for long term use	
	SOC4 – Other policy impact	Impact on other public policies (including potential conflicts with recommendations, economic efforts, etc.)	• -1: concordance / synergy • 0: no conflict • 1: low conflict • 2: moderate conflicts • 3: major conflicts	
Animal & Environmental Criteria (AEC)				
	AEC1 – Animal health impact	Impact on animal health and biodiversity = Type of effect * Scope * Value of species	Type of effect : • -1: health Improvement • 0: no effect • 1: morbidity • 2 : mortality Scope (number of species affected) : • 1: no species • 2: some species • 3: several species	Value of affected species (economic/ecological value, or endangered status) : • 1: low-value species or not at risk • 2: species of low values or susceptible species • 3: moderate value or vulnerable/of concern species • 4: important value of species or threatened/ endangered
	AEC2 – Environmental impact	Impact on physical environment and ecosystems = Type of effect * Scope * Value	Type of effect : • -1: improvement • 0: no effect • 1: low effect • 2: moderate effects • 3: High effects Geographic scope: • 1: none • 2: small scale • 3 large scale;	Value : • 1: none • 2 : terrestrial environment • 3 : aquatic environment • 4: terrestrial and aquatic environments • 5: complex ecosystems (water – air - ground)

SR4 - References used in the assessment of management interventions

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