Climate change and vector-borne disease emergence in Canada

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Climate Change Impacts on the Health of Canadians

- **temperature extremes:** heat related illnesses and deaths, respiratory and cardiovascular disorders
- **extreme climate events:** death, injury, illness, food/water shortage, contaminated water, displacement of populations etc.
- **air quality:** exacerbation of asthma, chronic obstructive pulmonary disease, increased risk of certain cancers
- **increased food- and water-borne disease incidence and outbreaks**
- **emergence/re-emergence of infectious diseases:** increased incidence of vector-borne disease, introduction of infectious diseases new to Canada


Canada in a changing climate - Sector perspectives on impacts and adaptation, 2014
Most (75%) EIDs are zoonoses
Woolhouse ME, Gowtage-Sequeria S. 2005 EID
Most affecting Canada have been zoonoses that emerged elsewhere in the world
(HIV, SARS, WNv, pH1N1, Lyme)
CLIMATE, CLIMATE CHANGE AND VBD EMERGENCE
How do infectious diseases emerge/re-emerge?

1. Human awareness (Lyme, SARS)
2. Introduction of exotic pathogens/vectors into existing suitable host/vector/human-contact ecosystem (SARS, West Nile)
3. Geographic spread from neighbouring endemic areas (Lyme, Rabies)
4. Ecological/environmental change causing endemic disease to increase in abundance/transmission and (for zoonoses) ‘spill-over’ into humans (Hantavirus, water-borne enteric disease)
5. True ‘emergence’: evolution and fixation of new, pathogenic genetic variants of previously benign microorganisms (pathogenic zoonotic influenzas)
Drivers for disease emergence and spread

Emergence.....Spillover....Spread
Global average surface temperature change

IPCC 2013

Mean over 2081–2100

(RCP2.6) RCP4.5 RCP6.0 RCP8.5
RCP 2.6
Change in average surface temperature (1986–2005 to 2081–2100)

RCP 8.5
Change in average surface temperature (1986–2005 to 2081–2100)

(b)
Change in average precipitation (1986–2005 to 2081–2100)

IPCC 2013
EXTREME WEATHER TRENDS: WHAT DO WE KNOW?

Understanding the Causes

- Hail
- Tornadoes
- Thunderstorm Winds
- Hurricanes
- Snow
- Floods
- Droughts
- Precipitation
- Heat Waves
- Cold Waves

Reliability of Observations

Source: Peterson et al., 2013.
Observed Global Mean Temperature Changes from 1850 to 2008 Relative to 1861-1899

Stott et al. 2010
Temperature distribution of mean temperatures during winter months, Stockholm

Grey = 1900-1929
Black = 1980-2009

Astrom et al. 2013
Climate change

Warming

Long term change in rainfall patterns

Climate variability and extreme weather events
Impact of climate on vector and vector-borne diseases

Randolph & Rogers Nature Rev Micro 2003

Ogden et al. J. Med. Entomol. 2004

Extrinsic incubation period

Ogden et al. Int. J. Parasitol. 2005
Arthropod vectors and the diseases they transmit

- **Insects:**
  - Mosquitoes: Malaria, Dengue, Chikungunya, West Nile virus
  - Fleas: Bartonellosis, Plague
  - Bugs: Chagas
  - Deer flies: Tularaemia
  - Blackflies: Onchercerciasis

- **Ticks**
  - Hard-bodied (Ixodid) ticks: Lyme, Babesiosis, Anaplasmosis, Ehrlichiosis, Powassan, Deer-tick virus, Rocky Mountain Spotted Fever
  - Soft-bodied (Argasid) ticks: Relapsing fever
Lifecycles of mosquitoes and ticks, and cycles of transmission of the diseases they carry

LC = 2.5 years
TC = 1 year

LC = 4 weeks
TC = 3 weeks
Ticks versus mosquitoes

- LC = 4 weeks
- TC = 3 weeks

- J = 2.5 years
- TC = 1 year
Ticks versus mosquitoes

LC = 2.5 years
TC = 1 year

LC = 4 weeks
TC = 3 weeks
Vector lifecycle characteristics determine disease patterns

Lyme disease
- Slow inexorable spread
- Then more or less constant risk

West Nile virus
- Rapid spread then epidemic behaviour

Ogden & Lindsay, Trends Parasitol 2016
Complex effects on zoonosis ecology: e.g. host communities, vector and host seasonality

- Many zoonoses (esp VBDs) are maintained by wildlife host communities indirectly affected by climate
- Vector seasonality due to temperature effects on development and activity
- Host demographic processes (reproduction, birth and mortality rates) are seasonal and affected directly indirectly (via resource availability) by climate

In Quebec: White-footed mouse range expanding,
Deer mouse range contracting
Simon et al. Evol Appl 2014

Changing climate alters tick seasonality and affects pathogen transmission
Biodiversity change

Ostfeld & Keesing 2000

Jones et al 2008

Jones et al 2012

Ogden & Tsao 2009

Reported Cases of Lyme Disease -- United States, 2001

Reported Cases of Lyme Disease -- United States, 2014
Climate change in developing countries: the four horsemen of the apocalypse

Burke et al. 2009 PNAS
A summary of expected VBD emergence events in Canada

Environ change + climatic variability: Epidemics/re-emergence of endemic VBD (WNV)

Environ change in Canada +
Environ change abroad:
Introduction of exotic VBDs & Zoonoses
AI, Chikungunya, Zika, Dengue, RVF, JE, Malaria

Environ change in North America: Northward spread of VBD Lyme, EEE, La Crosse, HME
OUR RESPONSES
Climate change and VBD - Adaptation

Vulnerability = Sensitivity + Exposure

Current Adaptation methods

Impacts without enhanced adaptation

Adaptation program

Vulnerability = Sensitivity + Exposure

Future Adaptation methods

Impacts with enhanced adaptation

PHAC role: enabling adaptation by P/T/Municipal public health
What is needed and what is practical

- Risk assessment
  - Ongoing assessment of priority VBDs for detailed study/surveillance
  - Assessment of where and when specific VBDs may emerge/re-emerge in Canada with projected climate change

- Surveillance for risks identified in previous programs:
  - Known emerging tick-borne diseases (Lyme, Babesia, HGE, Powassan)
  - Known emerging mosquito-borne diseases (EEE)
  - Known re-emerging (endemic) mosquito-borne diseases (WNV)
  - Possible emerging ticks/tick-borne diseases (Lone Star tick, HME)
  - Possible emerging mosquitoes/mosquito-borne diseases (Asian Tiger, La Crosse, Chikungunya etc.)
  - Possible re-emerging (endemic) mosquito-borne diseases (California serogroup viruses)

- Development of tools for P/T/municipal public health
  - Risk assessments so P/T/municipal public health can assess their own vulnerability
  - Knowledge and methods for P/T/municipal public health to undertake surveillance, prevention and control

- Research to support development of the above
RISK ASSESSMENT
PLUS SURVEILLANCE
Model-based risk assessment: doing the sums – putting together quantitative knowledge of the biology of VBD transmission cycles

Reservoir host dynamics

Host infection and transmission dynamics

Climate drivers

Agriculture dynamics

Vector biology

Combined GIS and statistical modelling

I am a Hantavirus and I was found here

Associated with:
- Climate
- Altitude
- Aspect
- Land use
- Agriculture
- Wildlife habitat
- Wildlife species
- Wildlife abundance
- Farm animal abundance

Driver zoonosis relationship

\[ P \approx \beta_1 \text{MinTM} + \beta_2 R + \beta_3 \text{MinSVP} + \beta_4 \text{MeanTX} + c \]

Uncertainty expressed in errors, confidence intervals etc.
Key determinants of Lyme disease risk

- Suitable habitat for ticks: assessed by field study (Ogden et al. JME 2006a)
- Suitable host densities: assessed previous field studies
- Dispersal of population-seeding ticks into Canada by migratory birds: assessed by surveillance/field study (Ogden et al. JME 2006b, AEM 2008)
- Temperature threshold for tick population persistence: obtained by simulation modelling (Ogden et al. 2005)
- Algorithm using temperature from GCMs and tick dispersion developed and mapped
Modelling Lyme vector spread with climate change

Ogden et al. Int. J. Health Geogr. 2008
Ogden et al. Environ Health Perspect 2014
Predictions consistent across climate model assemblage

McPherson et al. Environ Health Perspect 2016
Validation 1. Spatial pattern of *I. scapularis* invasion supports accuracy of model-derived temperature threshold for population persistence

Gabrie-Rivet et al. Plos One 2015
Validation 2: Spatial pattern of \textit{I. scapularis} invasion consistent with temperature and warming being a key driver

Leighton et al. 2012 J Appl Ecol

Ogden et al. 2008 Int J Hlth Geogr

Ogden et al. Environ Health Perspect 2010
Validation 3: Temporal pattern of *I. scapularis* invasion consistent with recent warming in Canada being a key driver

**Quebec**

Ogden et al. Environ Health Perspect 2014
McPherson et al. Environ Health Perspect 2017

Leighton et al. 2012 J Appl Ecol
Validation 4. Genuine range expansion identified by active surveillance

**Quebec** 2014 versus 2007/8

Ripoche et al. in prep

**Ontario** 2016 versus 2014/15

Clow et al. Plos One 2018

Clow et al. in prep
Spatiotemporal coincidence of *I. scapularis* invasion in Canada with warming – first evidence of VBD emergence with climate change?

Ogden et al. Environ Health Perspect 2014

“There has been an increasing number of cases of Lyme disease in Canada, and Lyme disease vectors are spreading along climate-determined trajectories” (Koffi et al., 2012; Leighton et al., 2012). UN-IPCC AR-5
Risk assessments: chikungunya and zika vector *Ae. albopictus*

Climatic indicator

Overwintering + annual mean temperature

Jan temp + summer temp + annual rainfall

Ogden et al. 2014 Parasites & Vectors

Without validation
Model based risk assessment for CHIKV and ZIKV transmission in Canada

Current climate

Legend:
- Canadian urban centres
- Unsuitable
- Rather unsuitable
- Partly suitable
- Rather suitable
Future projections

Near future (to 2040)

Far future (2041 - 2070)

Ng et al. 2017 EHP
Risk assessments: WNV and its vectors *Culex pipiens* & *Cx. tarsalis*


With validation

Without validation
Testing of suspect West Nile Virus negatives for California Serogroup virus antibody

- 649 sera tested in 2010
- 357 sera tested in 2011

- 163 IgG positive (25%)
- 61 IgM positive (9.3%)
- 80 IgG positive (22%)
- 35 IgM positive (9.8% IgM positive)

~ 200 WNV suspects tested from Ontario and Sask

~ 10% IgM +ve for JC / SSH
Emergence of EEE in eastern Canada

Rocheleau et al. 2017 Epidemiol Infect
PUBLIC HEALTH TOOLS
MCDA developed for prioritisation of climate sensitive zoonoses (Cox et al., 2012, 2013 PloS One)...being modified for our own internal processes
Public health tools: Tick surveillance and analysis methods

Koffi et al., 2012 J Med Entomol

Ogden et al., 2010 EHP

Assessment of a screening test to identify Lyme disease risk

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Public health tools: Sentinel surveillance for vector-borne diseases using deer/horses/dogs

*I. scapularis* and *Anaplasma phagocytophilum*: 
Bouchard et al 2013 J Med Entomol

Arboviruses (EEE, WNV, CSGV): 
Rocheleau et al. 2017 Epidem Infect
Public health tools: MCDA tool for decision-making on surveillance and control use

Lyme: Hongoh et al. 2011 Int J Health Geog MBD: Campagna et al., 2014 INSPQ

Implemented in QC, TRIaled in MB

Not used yet!
Public health tools: scoping and systematic reviews

RESEARCH ARTICLE
The Accuracy of Diagnostic Tests for Lyme Disease in Humans, A Systematic Review and Meta-Analysis of North American Research
Lisa A. Waddell1,2,*, Judy Greig1,6, Mariola Mascarenhas1,6, Shannon Harding1,6, Robbin Lindsay21, Nicholas Ogden21

Tropical Medicine and Health

REVIEW
Risk perceptions, attitudes, and knowledge of chikungunya among the public and health professionals: a systematic review

RESEARCH ARTICLE
Scoping Review of the Zika Virus Literature
Lisa A. Waddell1,2,*, Judy D. Greig1,6
1 National Microbiology Laboratory at Guelph, Public Health Agency of Canada, Guelph, Ontario, Canada,
2 Department of Population Medicine, University of Guelph, Guelph, Ontario, Canada
Public health tools: WNV forecasting

Forecasting WNV risk in the east:
Wang et al. 2011 J Med Entomol

Implemented in GTA
Generalisability being assessed

Forecasting WNV risk in the prairies:
Chen et al. 2011 J Med Entomol

Implemented in Saskatchewan
Concluding points

- Risk assessments indicate risk of emergence of VBD via spread from neighbouring regions of US
- Risk of exotic/tropical VBD transmission low but not zero
- Surveillance has shown that Lyme and EEE have emerged in Canada
- Epidemic re-emergence of WNV is occurring with climate warming and variability
- Risk assessments and tools developed to assist Provinces and Territories to have greater adaptive capacity
- Tools include information on surveillance and control methods, decision analysis methods and forecasting models
- Dissemination of these tools remains a challenge to their uptake and use