Public Health Agency of Canada | Agence de la santé publique du Canada

Canada

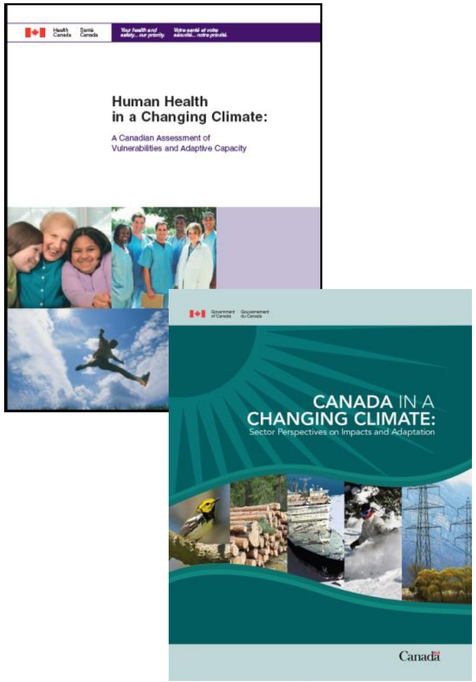
Climate change and vector-borne disease emergence in Canada

Nick H. Ogden, National Microbiology Laboratory

PROTECTING AND EMPOWERING CANADIANS
TO IMPROVE THEIR HEALTH

Climate Change Impacts on the Health of Canadians

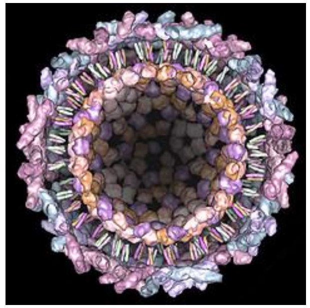
- **temperature extremes:** heat related illnesses and deaths, respiratory and cardiovascular disorders
- **extreme climate events:** death, injury, illness, food/water shortage, contaminated water, displacement of populations etc.
- **air quality:** exacerbation of asthma, chronic obstructive pulmonary 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



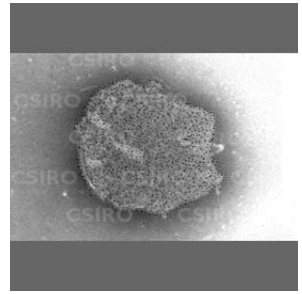
Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity, 2008

Canada in a changing climate - Sector perspectives on impacts and adaptation, 2014

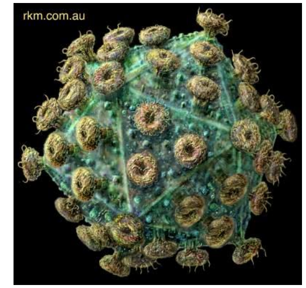
Lyme



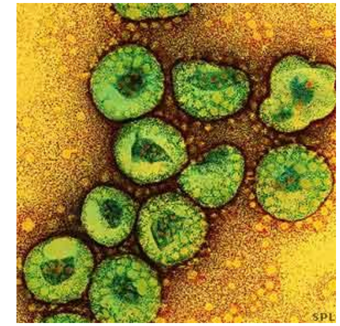
Chikungunya



Hendra



HIV



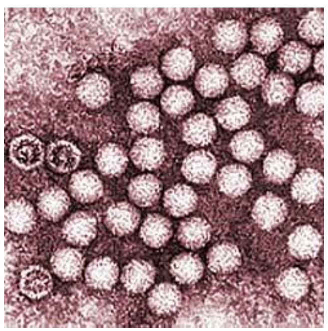
SARS

Most (75%) EIDs are zoonoses

Woolhouse ME, Gowtage-Sequeria S. 2005 EID

Most affecting Canada have been zoonoses that emerged elsewhere in the world

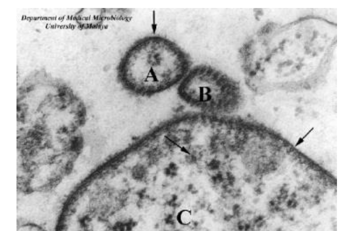
(HIV, SARS, WNv, pH1N1, Lyme)



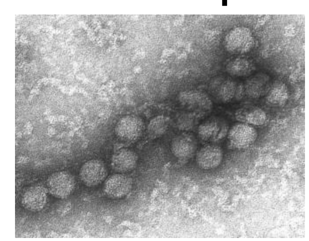
RVF

Chikungunya vector

Lyme vector



Nipah



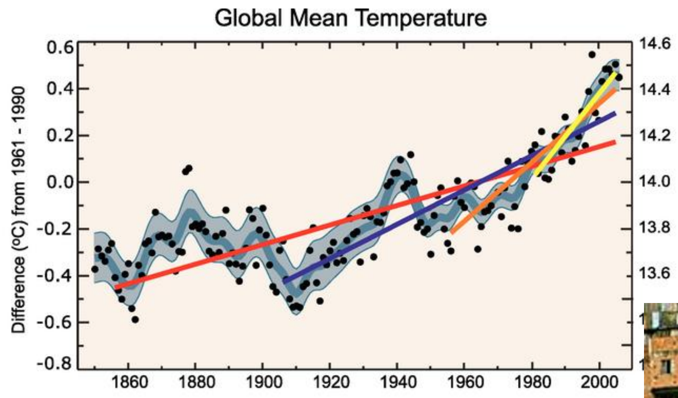
WNV

CLIMATE, CLIMATE CHANGE AND VBD EMERGENCE

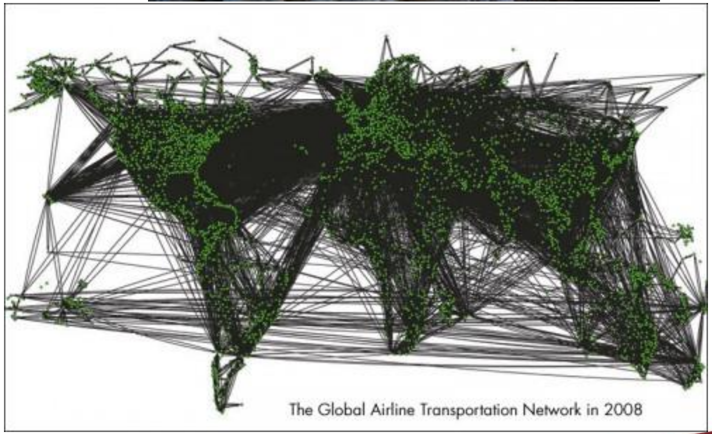
How do infectious diseases emerge/re-emerge?

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)

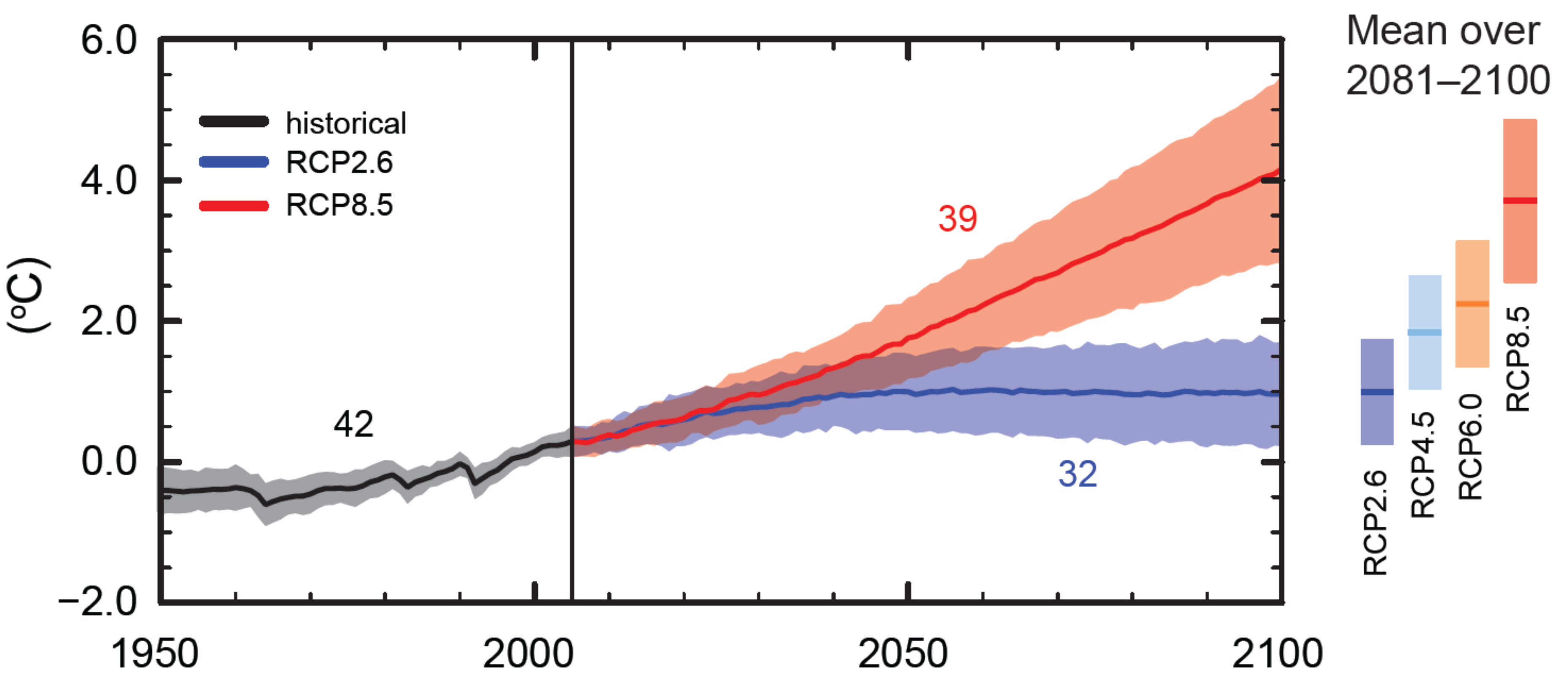
Drivers for disease emergence and spread



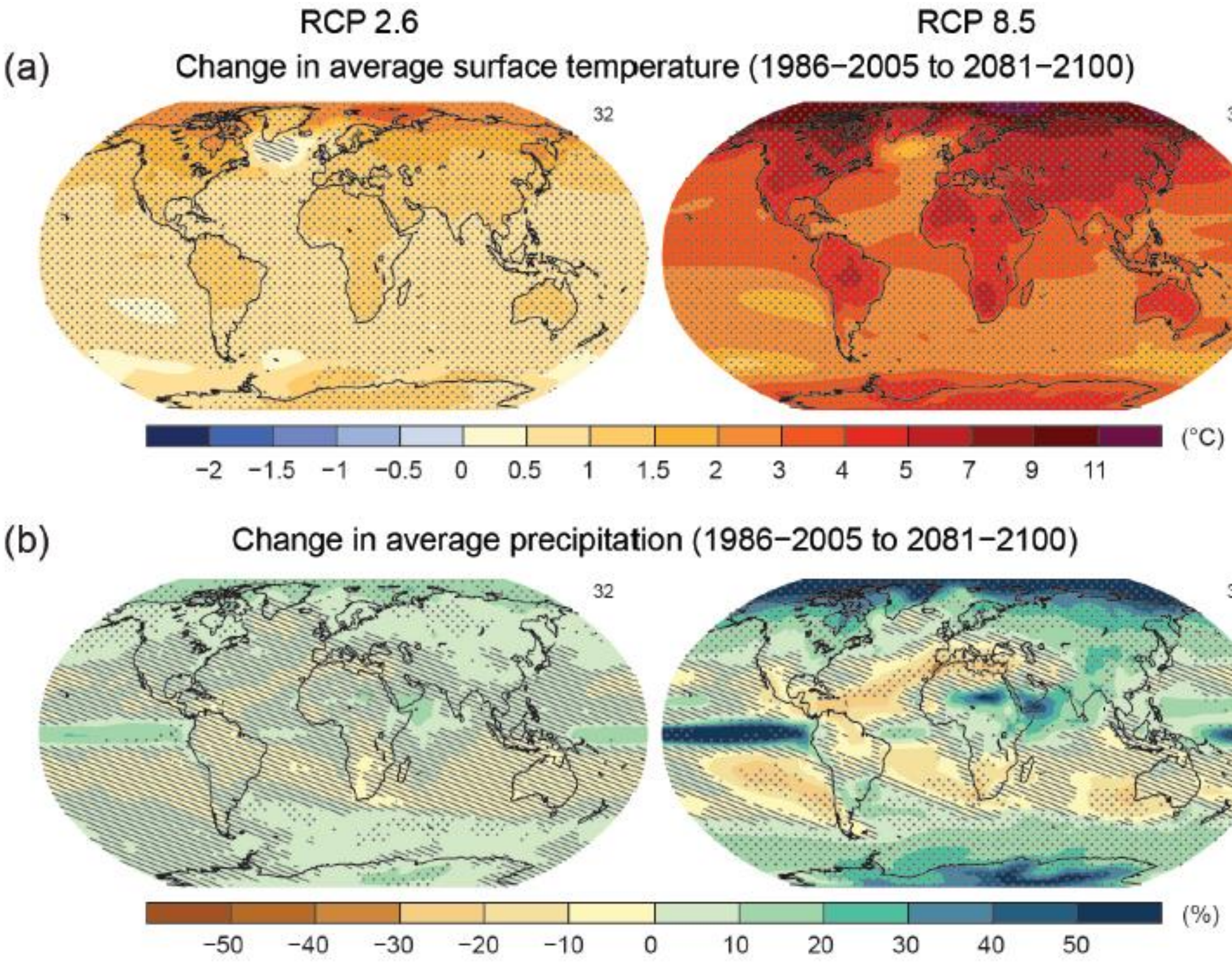
Emergence…..Spillover….Spread



Global average surface temperature change

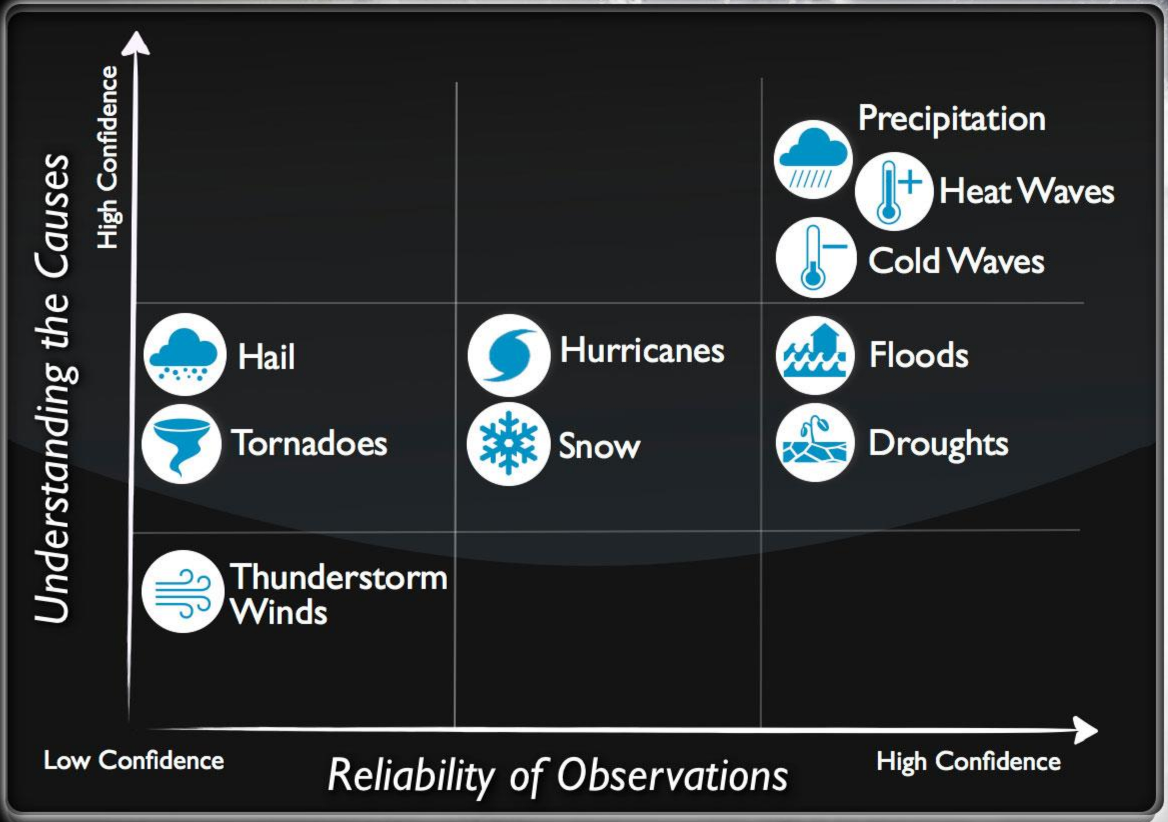


IPCC 2013


RCP 2.6
RCP 8.5
(a)
Change in average surface temperature (1986−2005 to 2081−2100)
32
39
(°C)
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(b)
Change in average precipitation (1986−2005 to 2081−2100)
32
39
(%)
−50 −40 −30 −20 −10 0 10 20 30 40 50

IPCC 2013

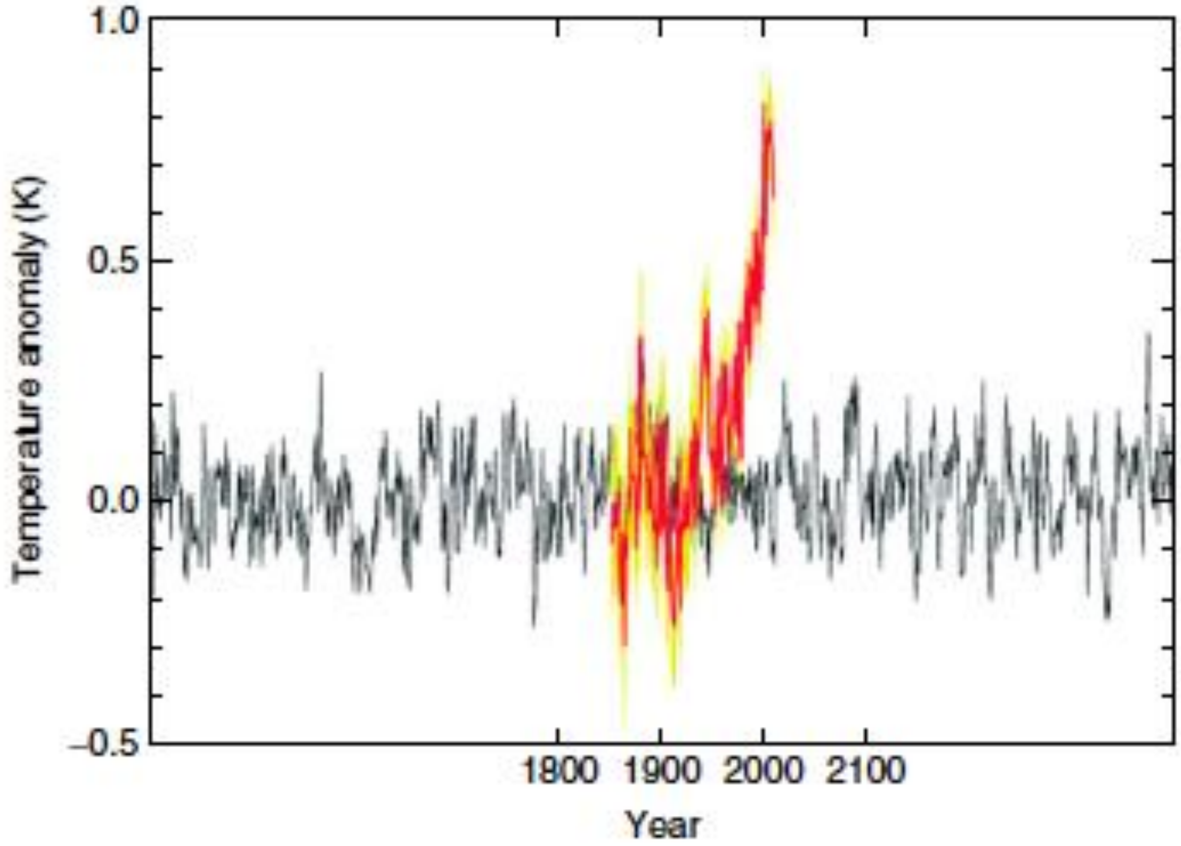
Extreme Weather Trends: What Do We Know?



Source: Peterson et al., 2013.

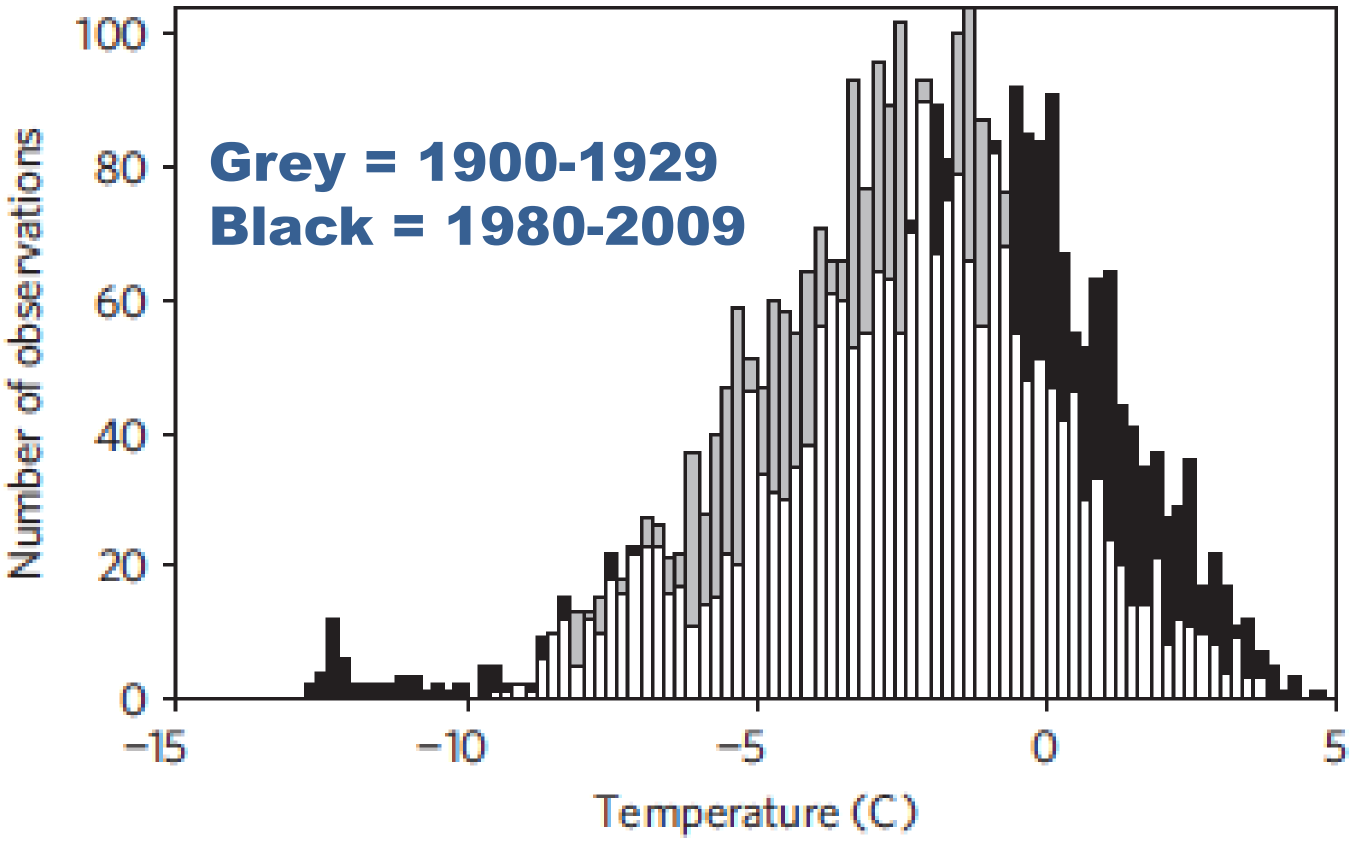
CLIMATE CENTRAL

Observed Global Mean Temperature Changes from 1850 to 2008 Relative to 1861-1899



Stott et al. 2010

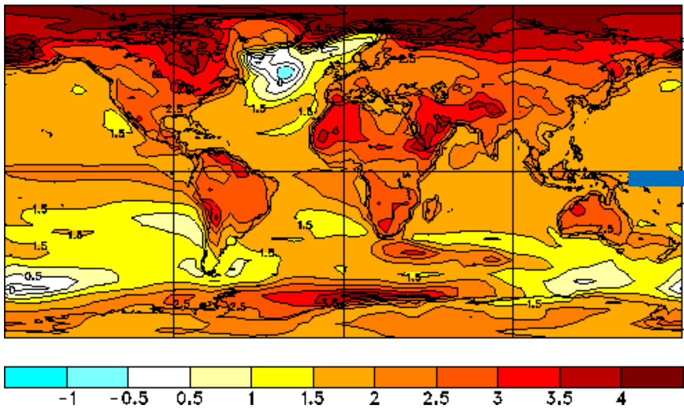
Temperature distribution of mean temperatures during winter months, Stockholm

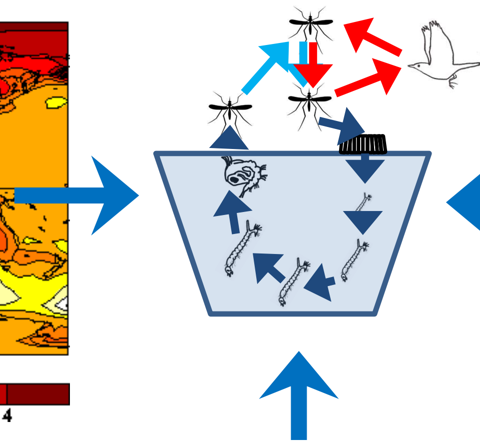


Astrom et al. 2013

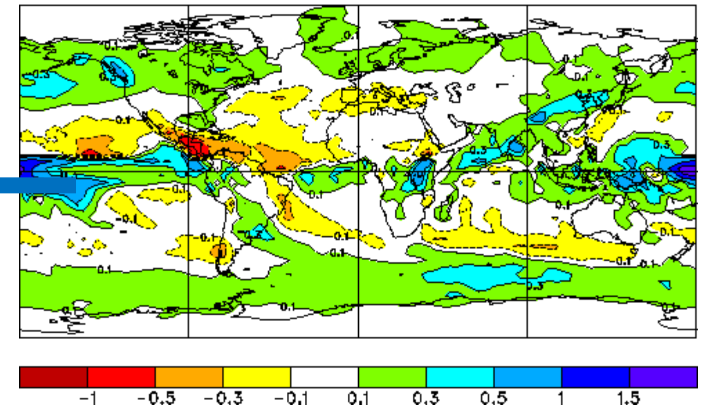
Climate change

Warming

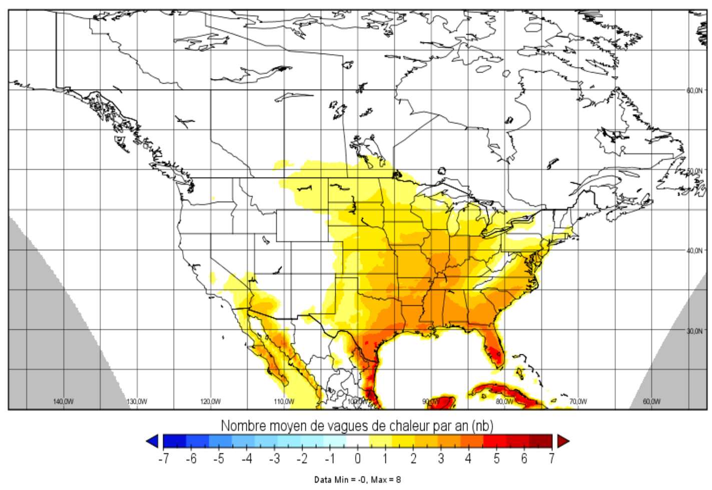




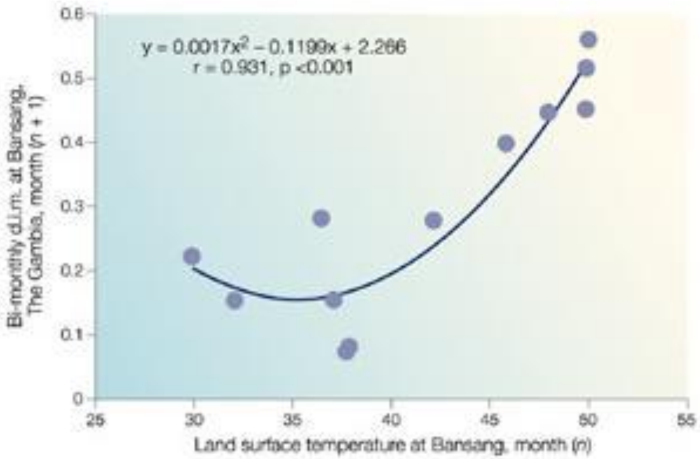
Long term change in rainfall patterns



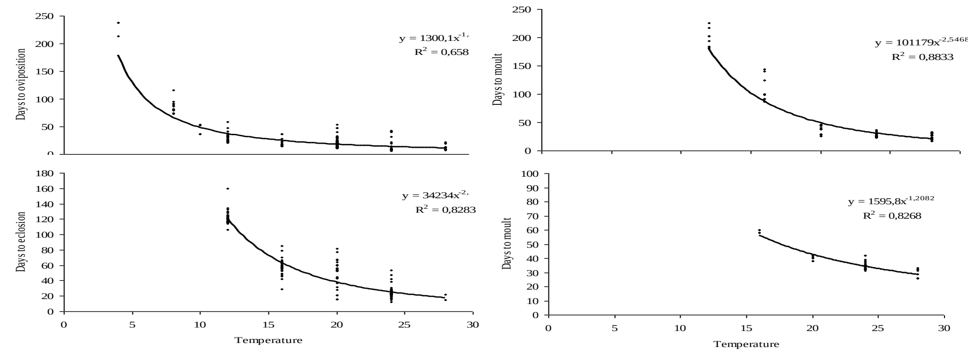
Climate variability and extreme weather events



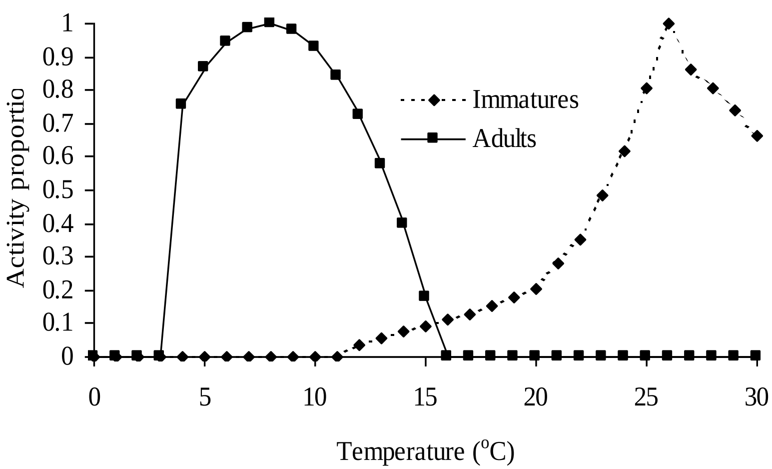
Impact of climate on vector and vector-borne diseases



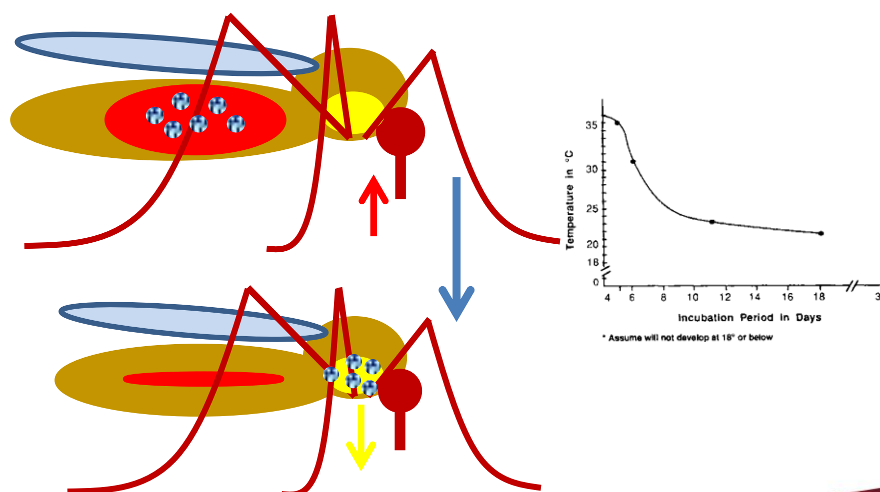
Randolph & Rogers Nature Rev Micro 2003



Ogden et al. J. Med. Entomol. 2004



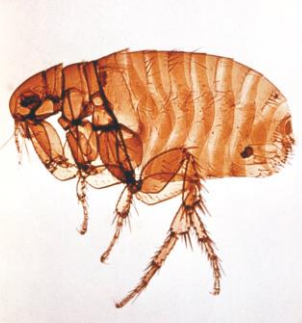
Ogden et al. Int. J. Parasitol. 2005



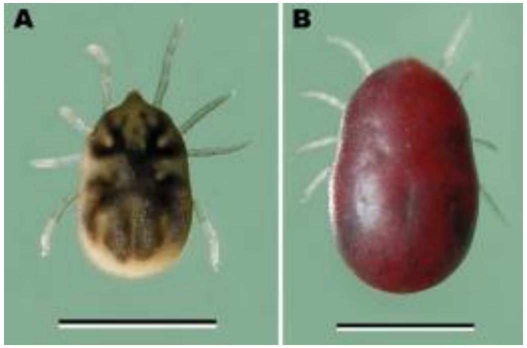
Extrinsic incubation period

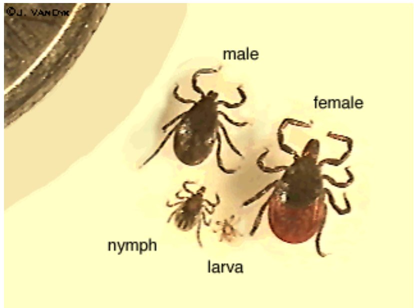
Arthropod vectors and the diseases they transmit

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

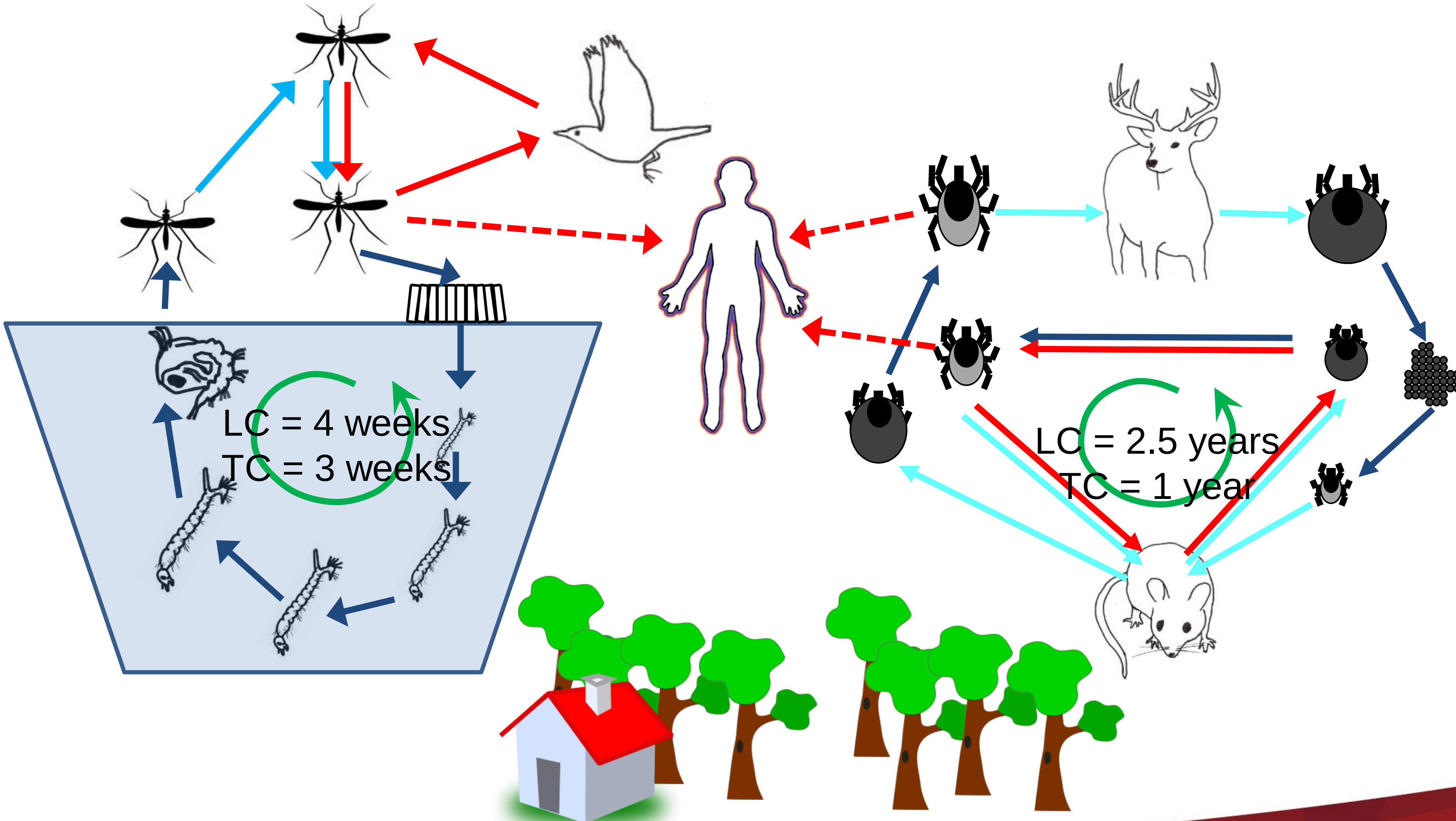


- Ticks
  - Hard-bodied (Ixodid) ticks : Lyme, Babesiosis, Anaplasmosis, Ehrlichiosis, Powassan, Deer-tick virus, Rocky Mountain Spotted Fever
  - Soft-bodied (Argasid) ticks: Relapsing fever

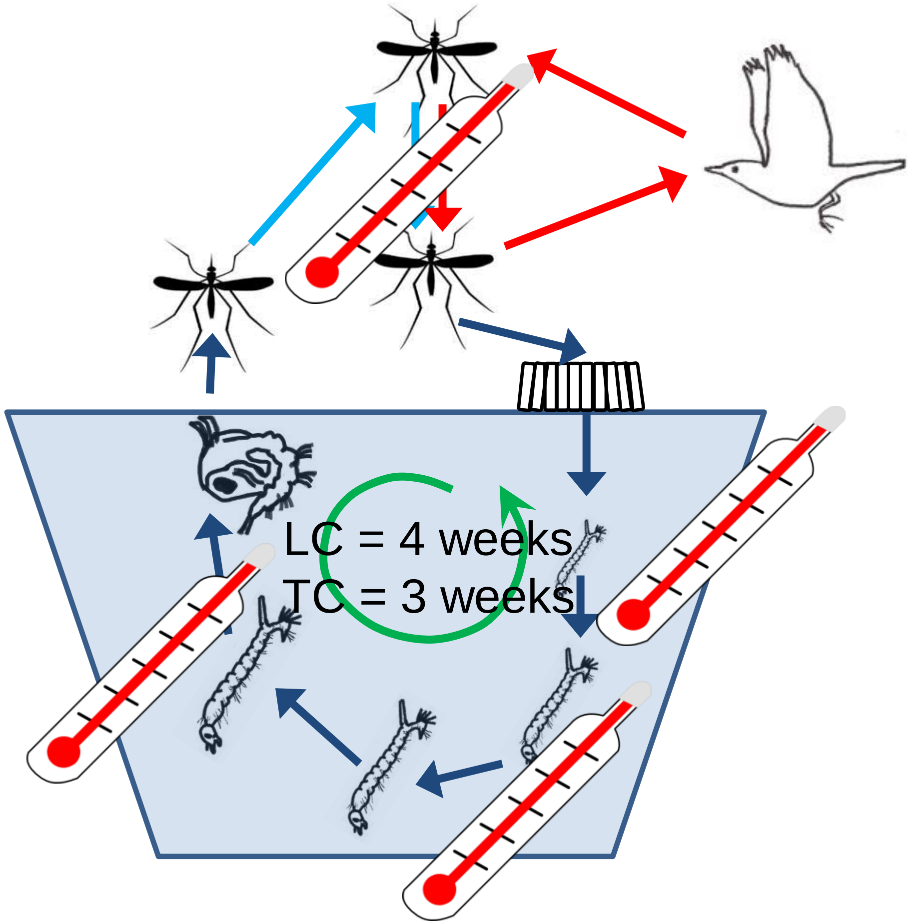


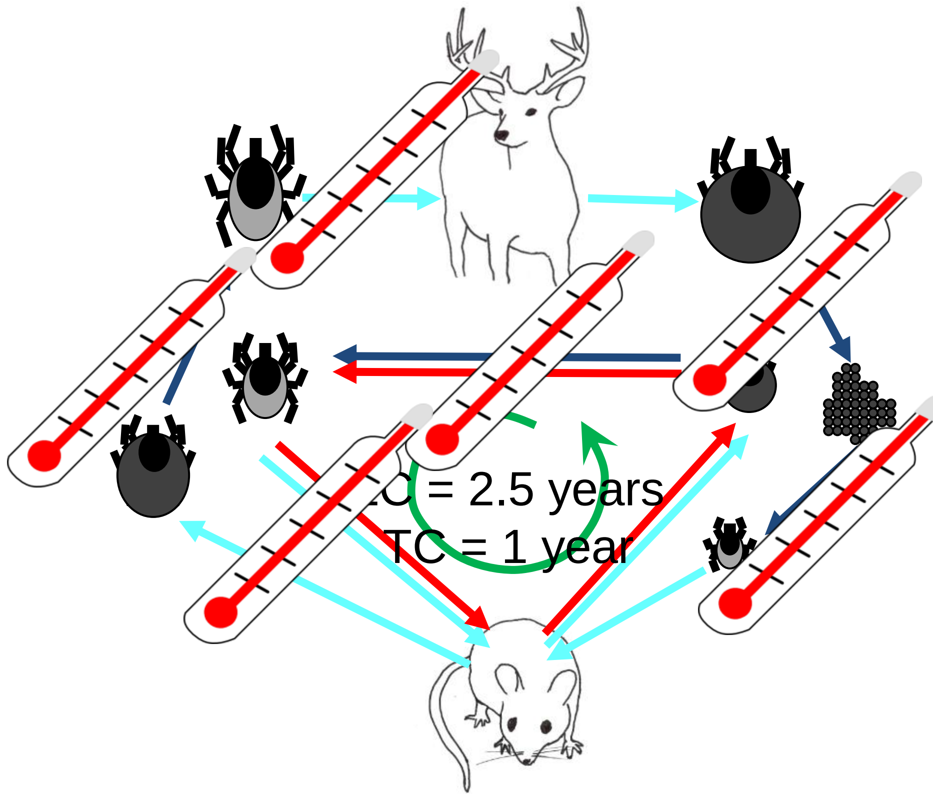


Lifecycles of mosquitoes and ticks, and cycles of transmission of the diseases they carry

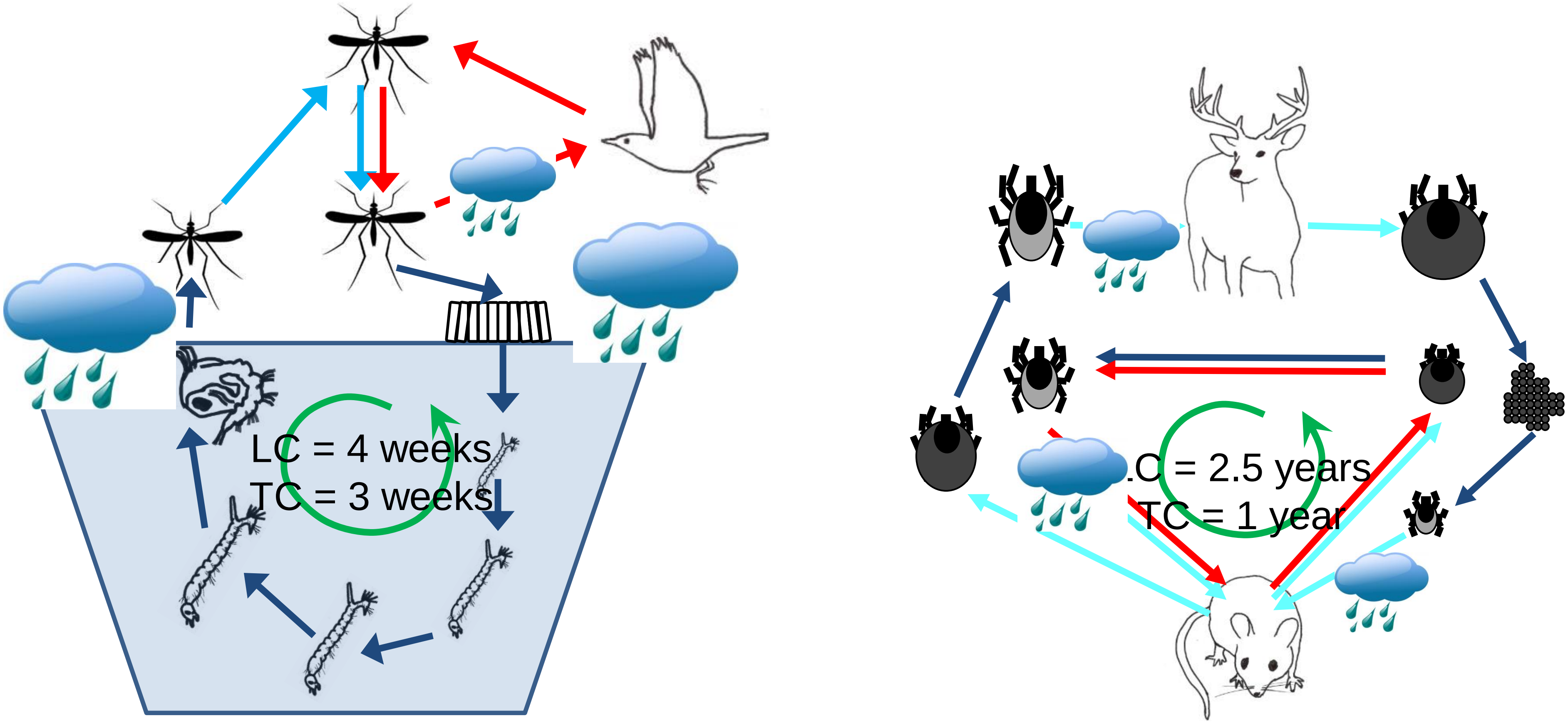


Ticks versus mosquitoes

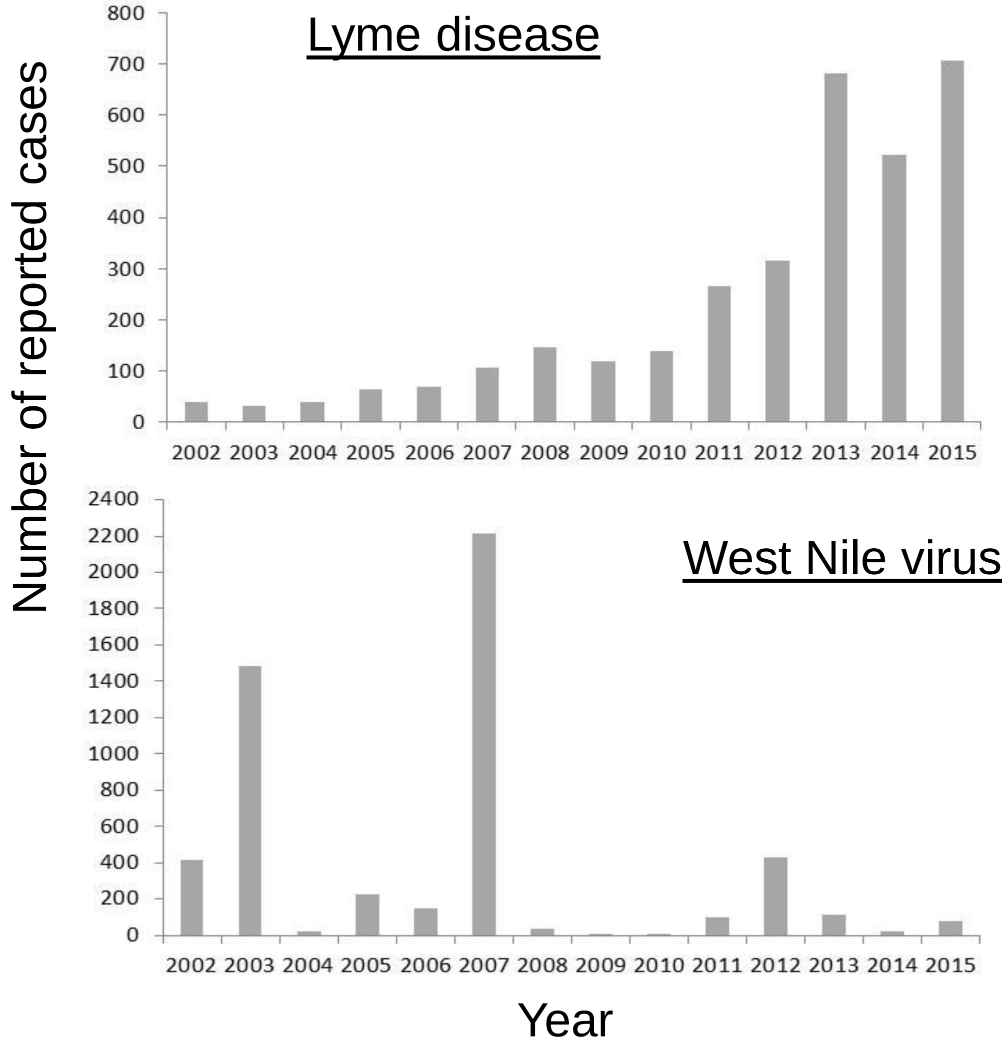




Ticks versus mosquitoes



Vector lifecycle characteristics determine disease patterns



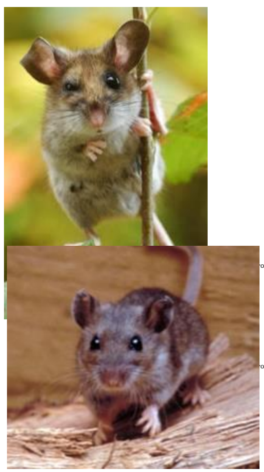
Slow inexorable spread then more or less constant risk

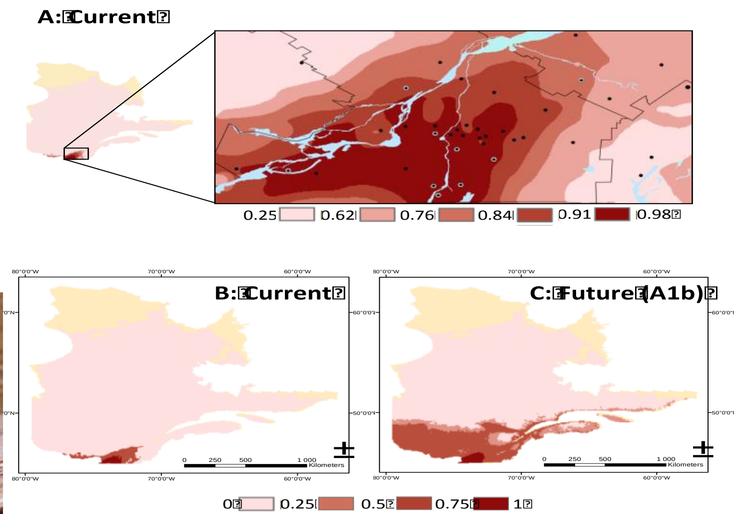
Rapid spread then epidemic behaviour

Ogden & Lindsay, Trends Parasitol 2016

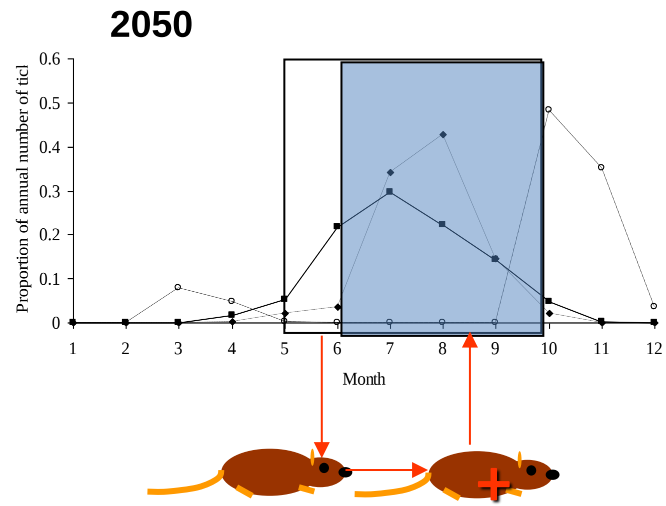
Complex effects on zoonosis ecology: e.g. host communities, vector and host seasonality

- 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



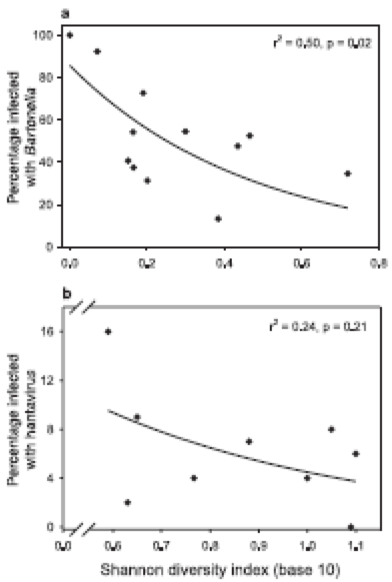


In Quebec: White-footed mouse range expanding, Deer mouse range contracting
Simon et al. Evol Appl 2014

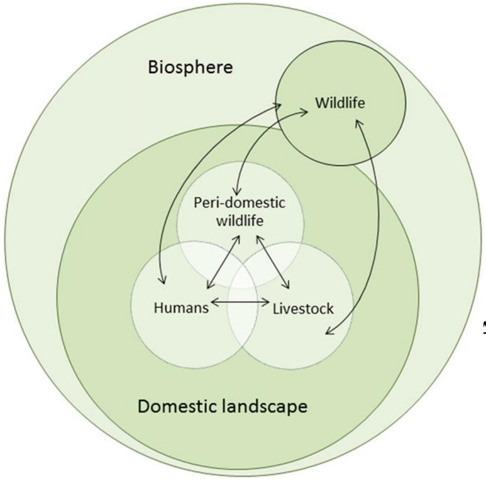


Changing climate alters tick seasonality and affects pathogen transmission
Ogden et al., J. Theor Biol. 2008; Kurtenbach et al. Nature Rev. Microbiol. 2006

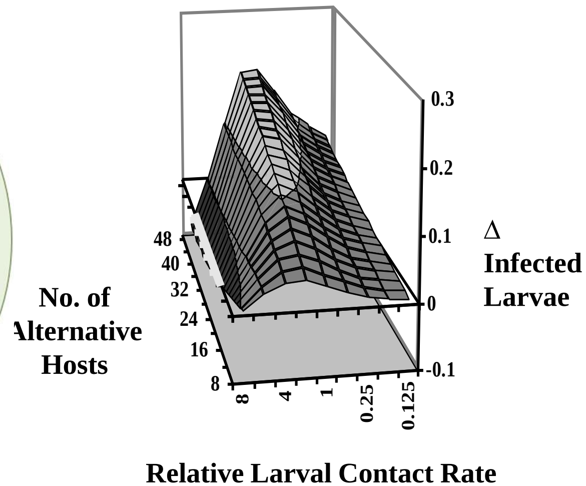
Biodiversity change



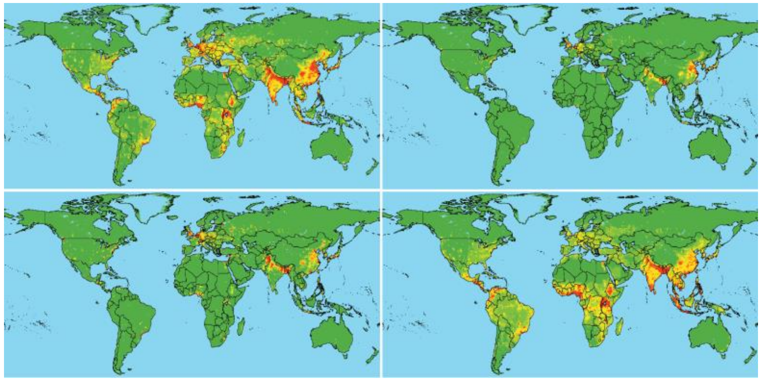
Ostfeld & Keesing 2000



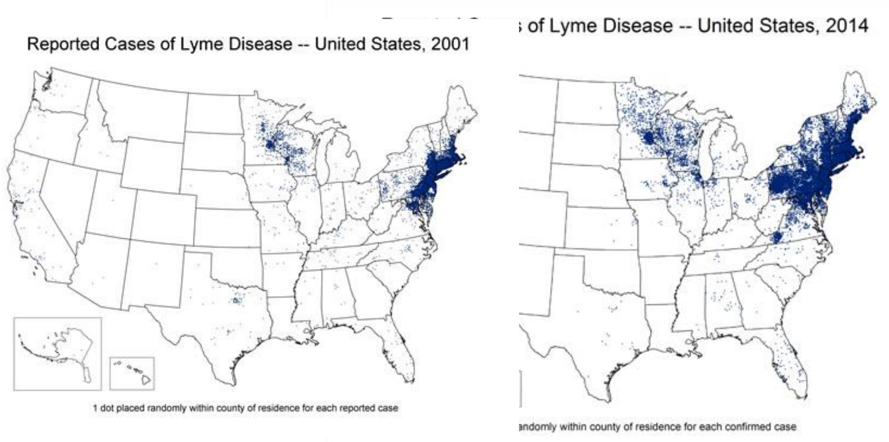
Jones et al 2012



Ogden & Tsao 2009



Jones et al 2008



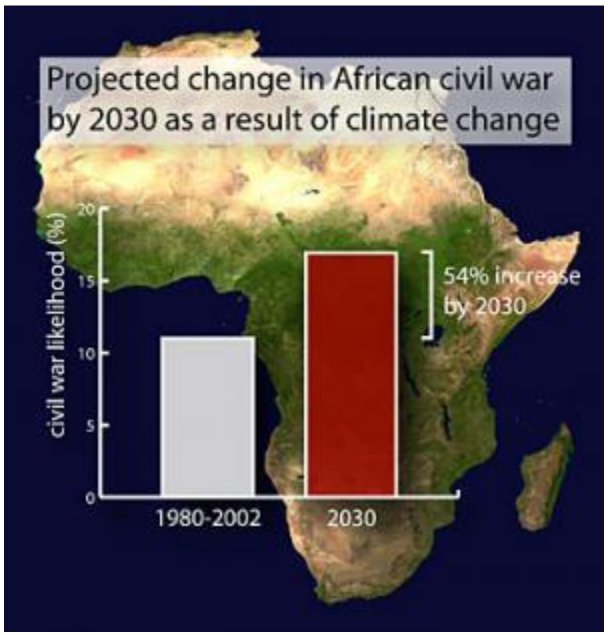
Climate change in developing countries: the four horsemen of the apocalypse

Climate Change → Famine → War → Pestilence

Famine, War, Pestilence → Death in developing countries

Famine, War, Pestilence → Reduced capacity to control + migration

Reduced capacity to control + migration → Immigration and import of exotic VBD
Malaria, Dengue, Chikungunya

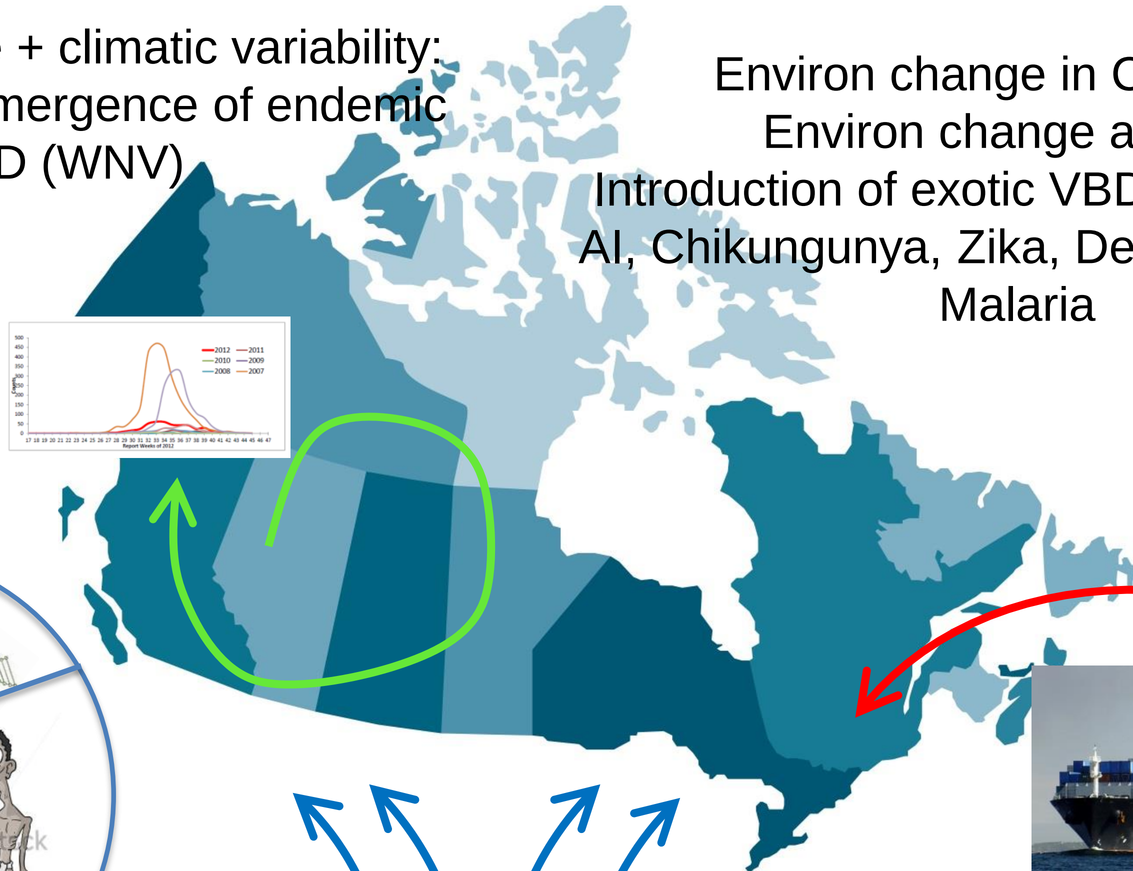


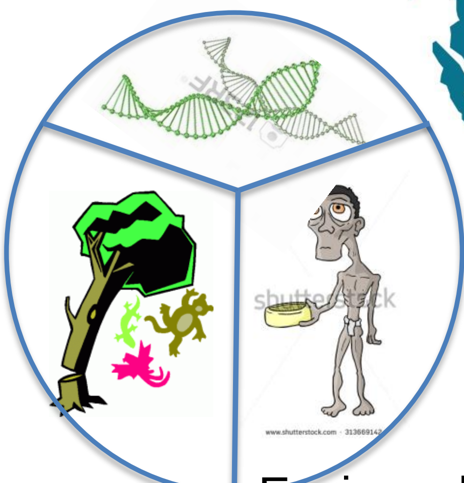
Burke et al. 2009 PNAS

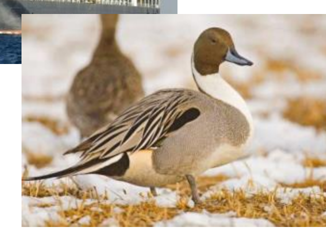
A summary of expected VBD emergence events in Canada

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



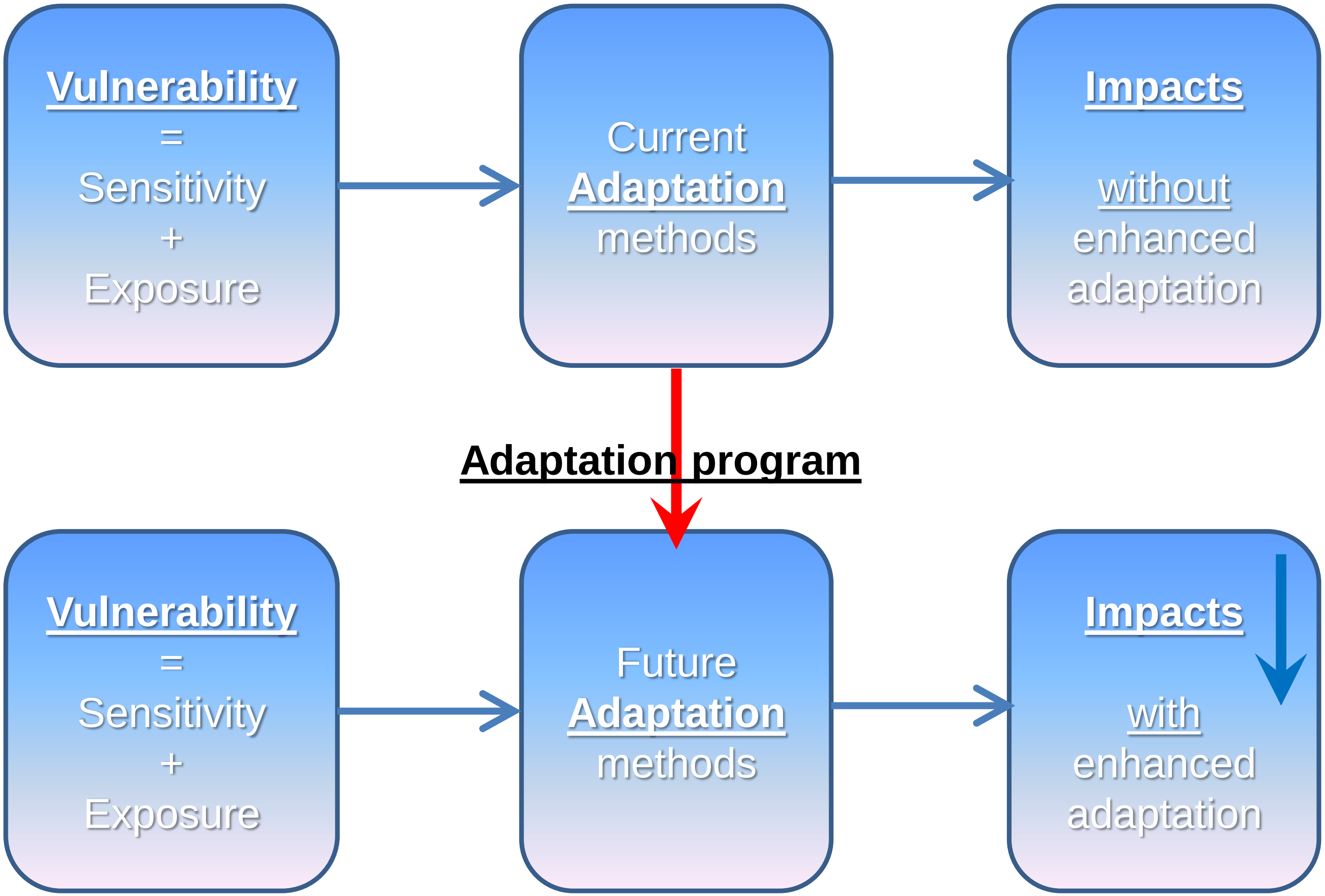




Environ change in North America: Northward spread of VBD Lyme, EEE, La Crosse, HME

OUR RESPONSES

Climate change and VBD - Adaptation



PHAC role: enabling adaptation by P/T/Municipal public health

What is needed and what is practical

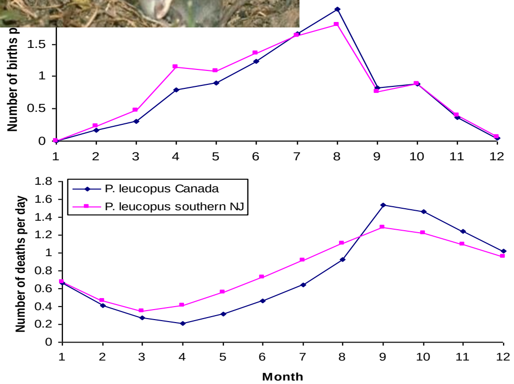
- Risk assessment
  - Ongoing assessment of priority VBDs for detailed study/surveillance
  - Assessment of where and when specific VBDs may emerge/re-emerge in Canada with projected climate change
- Surveillance for risks identified in previous programs:
  - Known emerging tick-borne diseases (Lyme, 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

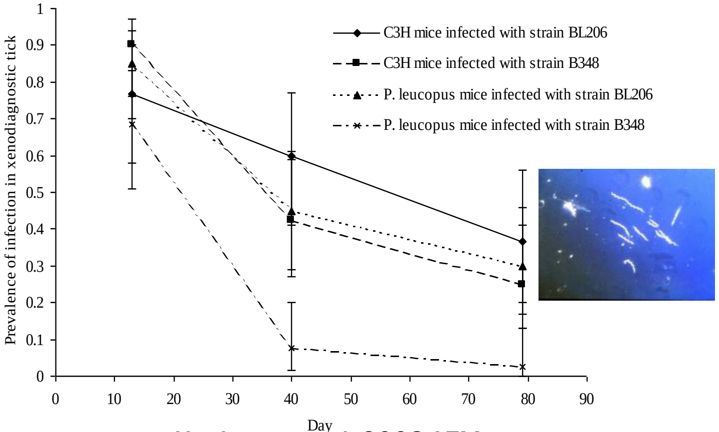
Climate drivers

Reservoir host dynamics



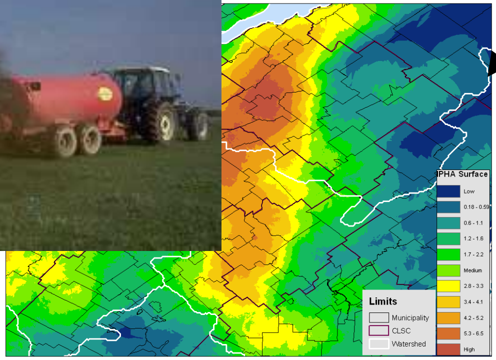
Ogden et al. 2007 Parasitology

Host infection and transmission dynamics



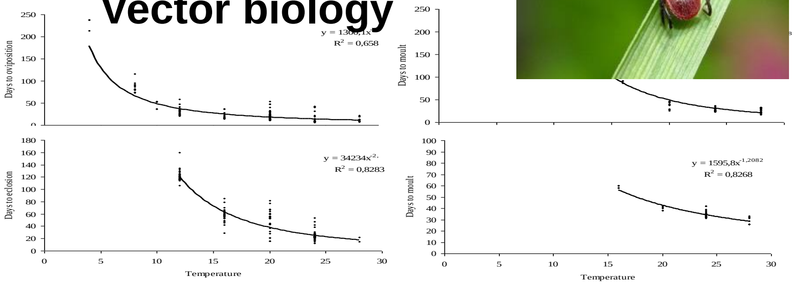
Hanincova et al. 2008 AEM

Agriculture dynamics



Ravel et al. Int J Hygiene Env Health 2004

Vector biology



I. scapularis development: Ogden et al. J. Med. Entomol. 2004

Combined GIS and statistical modelling

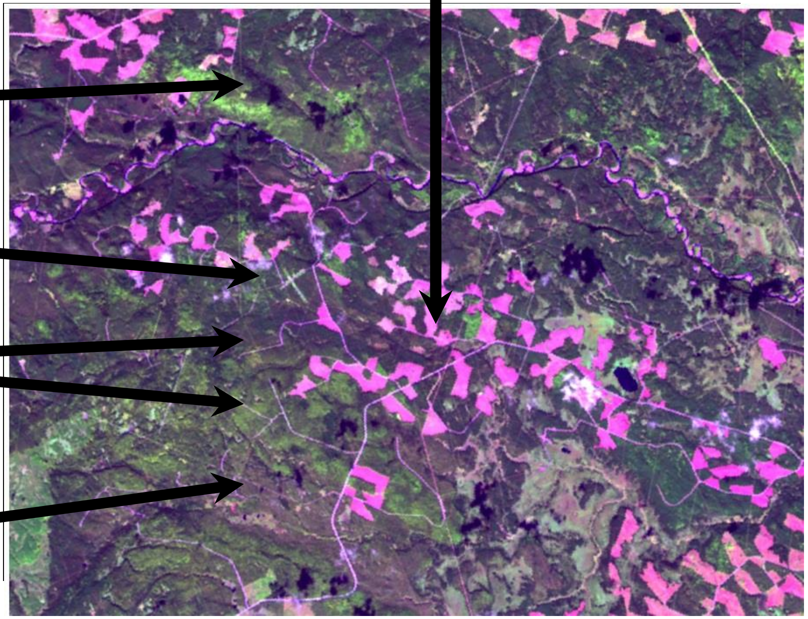
I am a Hantavirus and I was found here

Here

Here

Not Here

Here



Associated with:

Climate
Altitude
Aspect
Land use
Agriculture
Wildlife habitat
Wildlife species
Wildlife abundance
Farm animal abundance

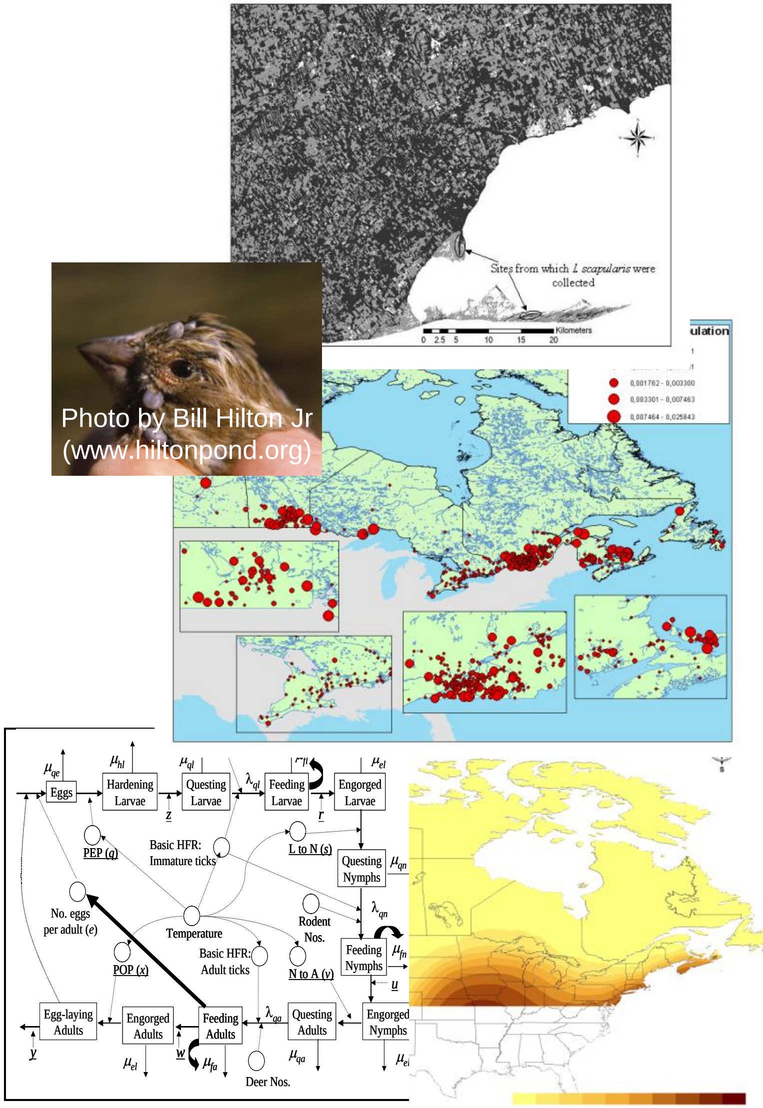
Driver zoonosis relationship

Uncertainty expressed in errors, confidence intervals etc.

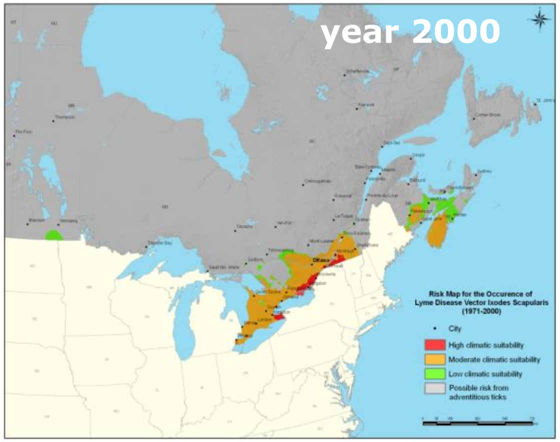
$$P \approx \beta_1 MinTM + \beta_2 R + \beta_3 MinSVP + \beta_4 MeanTX + c$$

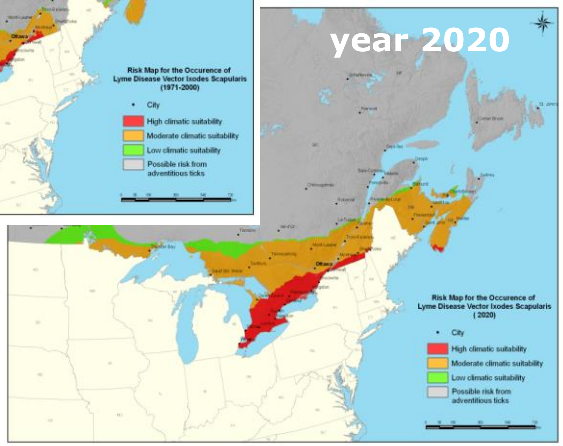
Key determinants of Lyme disease risk

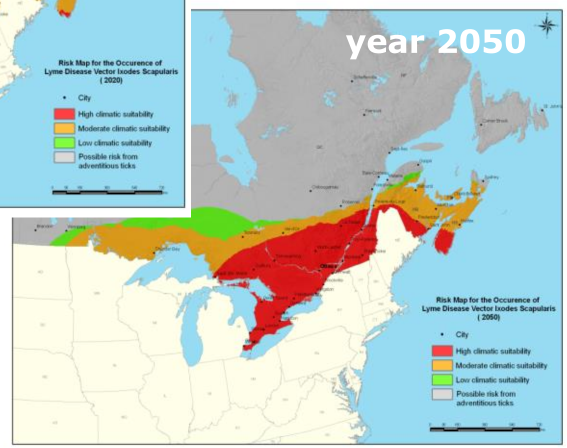
- Suitable habitat for ticks: assessed by field study (Ogden et al. JME 2006a)
- Suitable host densities: assessed previous field studies
- Dispersal of population-seeding ticks into Canada by migratory birds: assessed by surveillance/field study (Ogden et al. JME 2006b, AEM 2008)
- Temperature threshold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

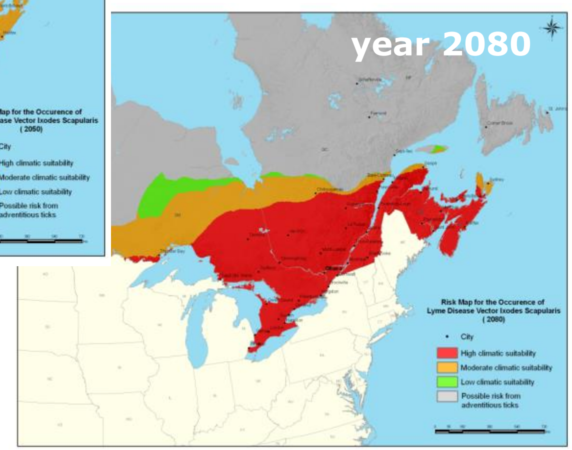


Modelling Lyme vector spread with climate change



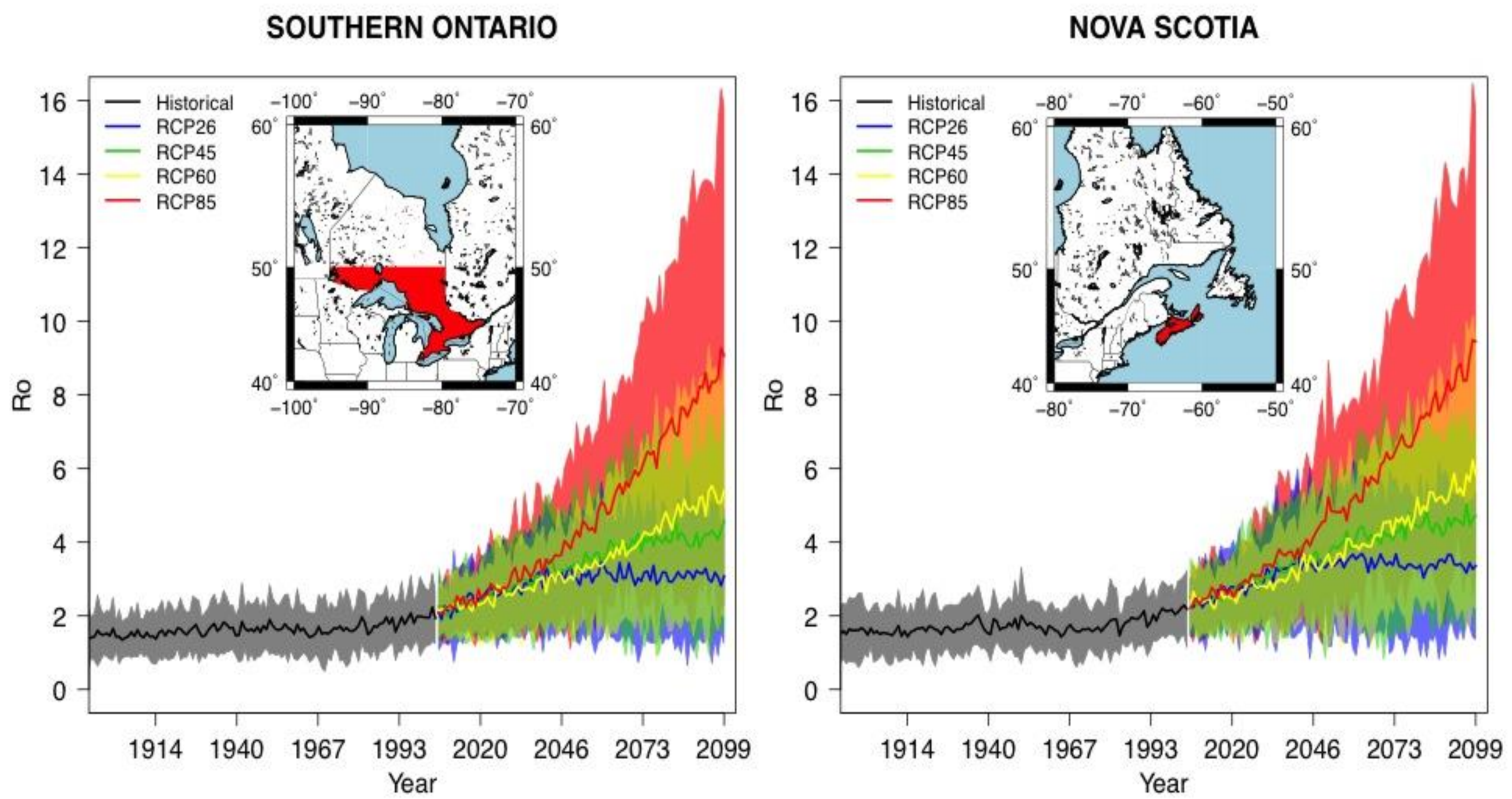




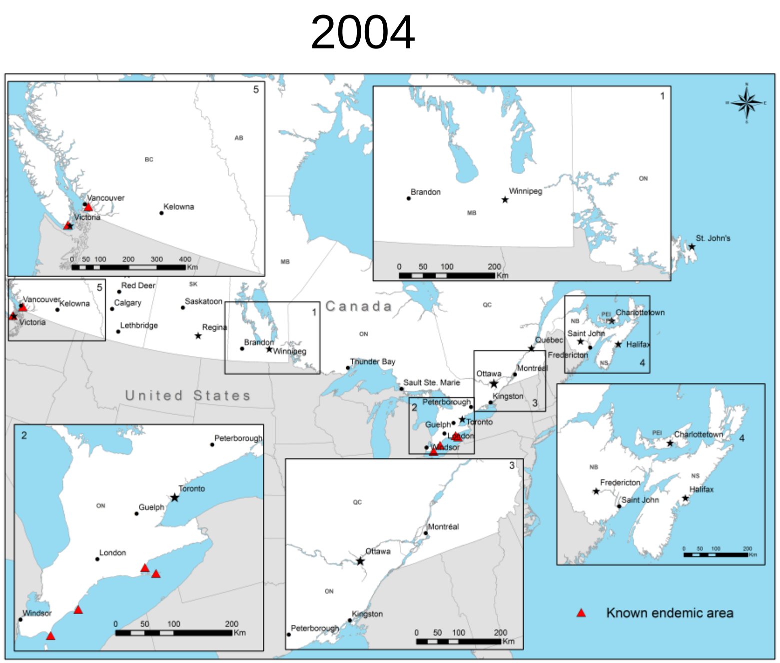


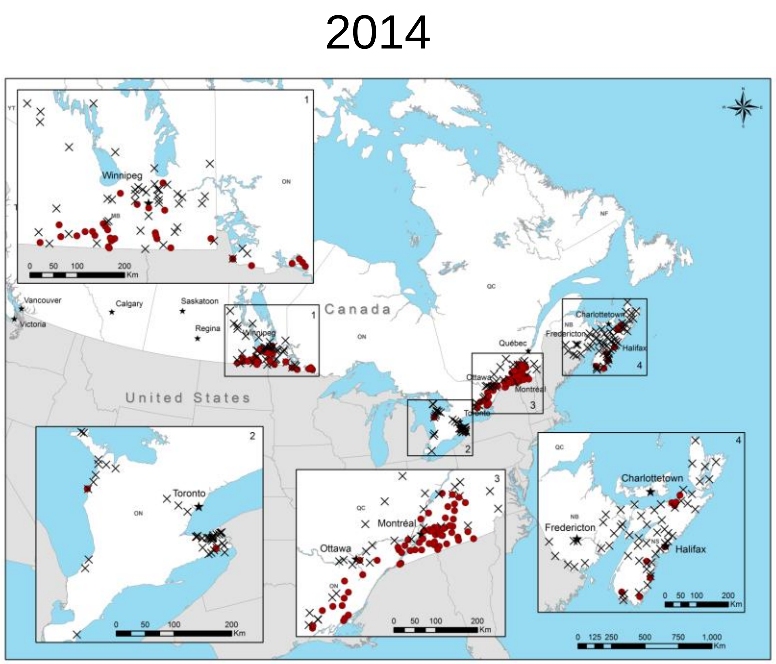
Ogden et al. Int. J. Health Geogr. 2008
Ogden et al Environ Health Perspect 2014

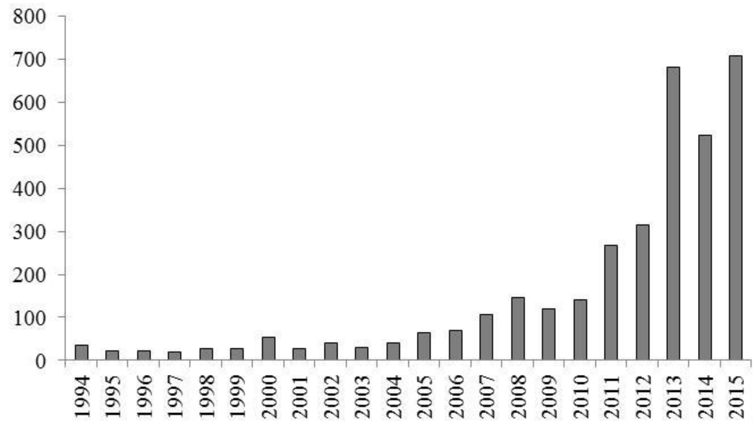
Predictions consistent across climate model assemblage



McPherson et al. Environ Health Perspect 2016


2004
Canada
United States
Known endemic area


2014
Canada
United States


800
700
600
500
400
300
200
100
0
1994
1995
1996
1997
1998
1999
2000
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2002
2003
2004
2005
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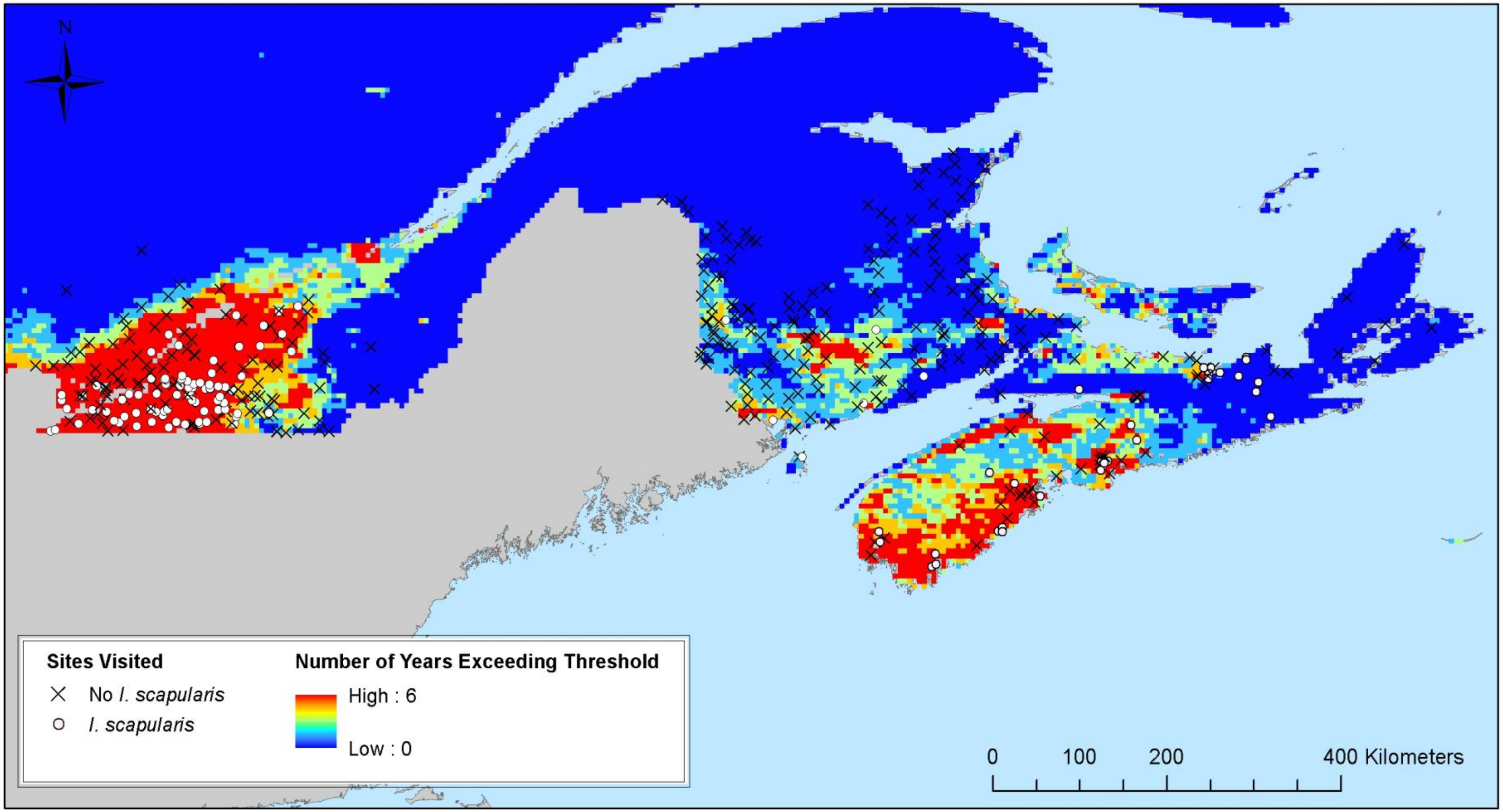
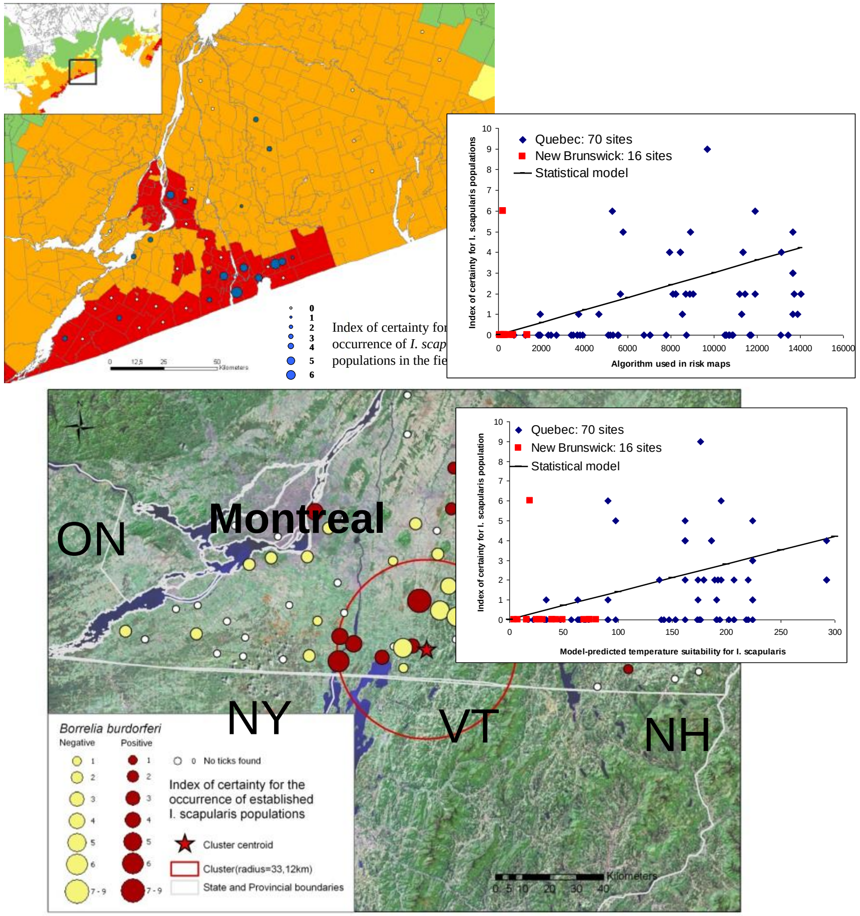
2009
2010
2011
2012
2013
2014
2015

Validation 1. Spatial pattern of *I. scapularis* invasion supports accuracy of model-derived temperature threshold for population persistence

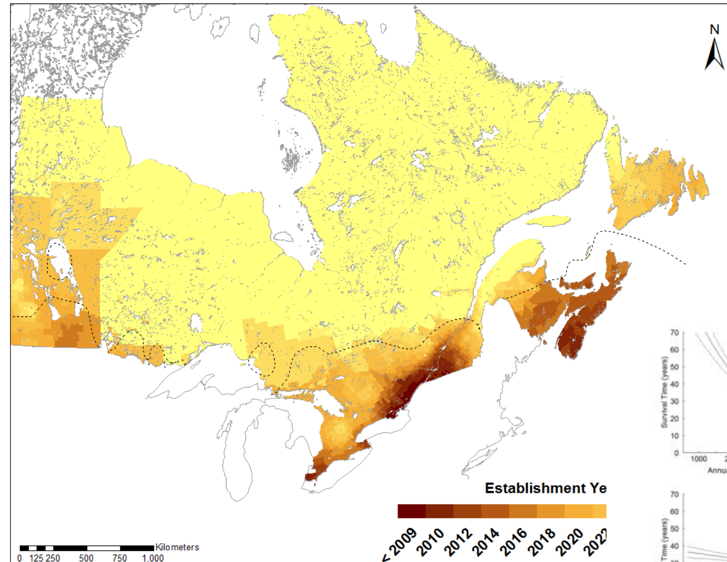


Gabrie-Rivet et al. Plos One 2015

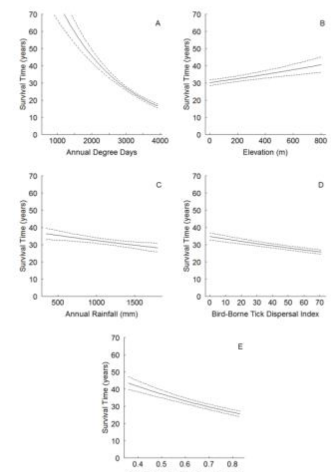
Validation 2: Spatial pattern of *I. scapularis* invasion consistent with temperature and warming being a key driver



Ogden et al. 2008 Int J Hlth Geogr



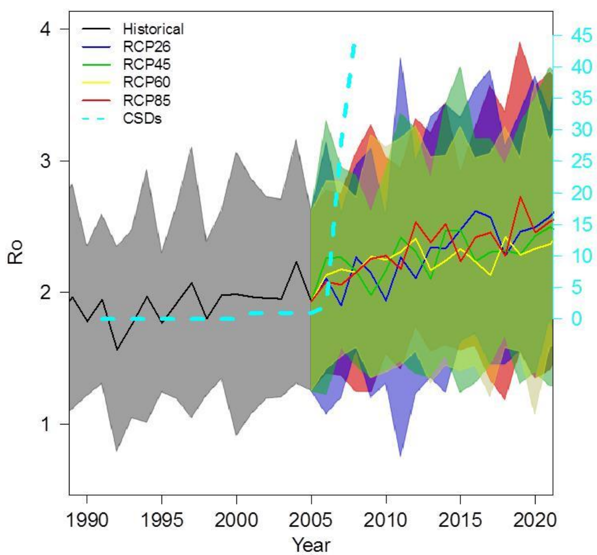
Leighton et al. 2012 J Appl Ecol



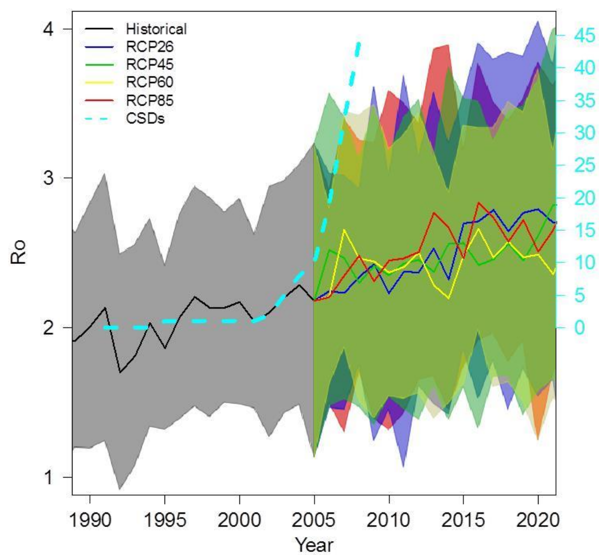
Ogden et al. Environ Health Perspect 2010

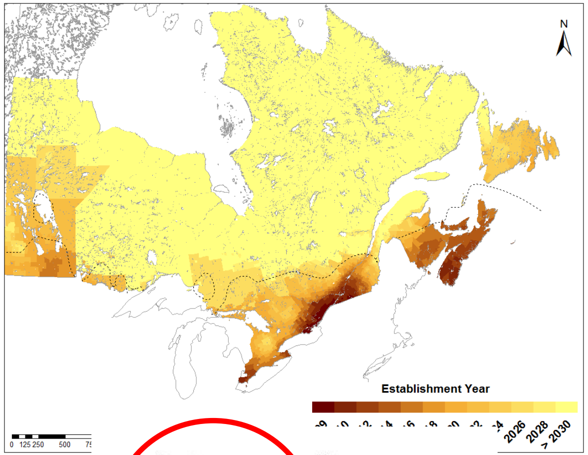
Validation 3: Temporal pattern of *I. scapularis* invasion consistent with recent warming in Canada being a key driver

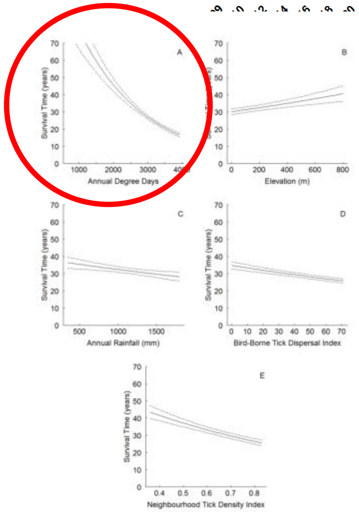
SOUTHERN ONTARIO



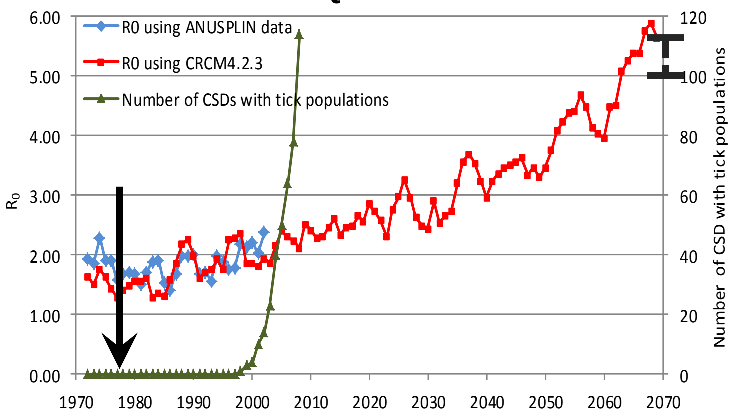
NOVA SCOTIA







QUEBEC



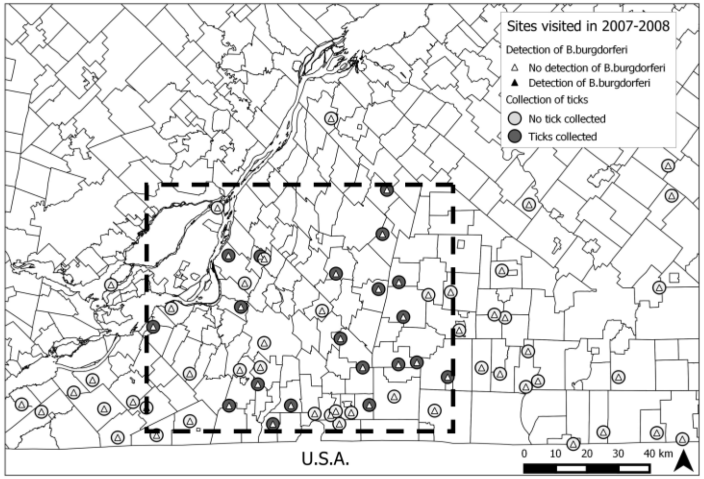
Leighton et al. 2012 J Appl Ecol

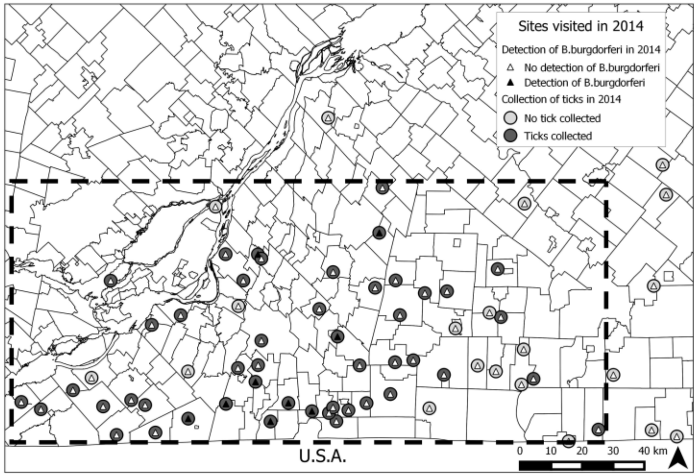
Ogden et al. Environ Health Perspect 2014

McPherson et al. Environ Health Perspect 2017

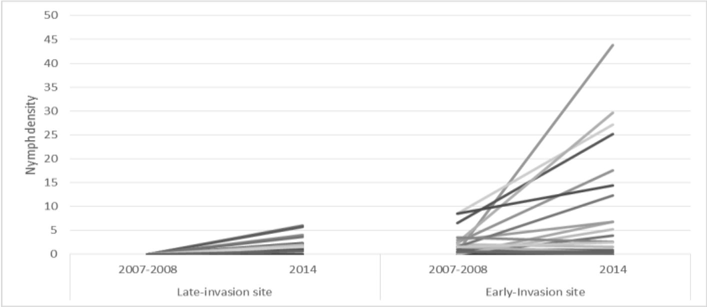
Validation 4. Genuine range expansion identified by active surveillance

<u>Quebec</u> 2014 versus 2007/8

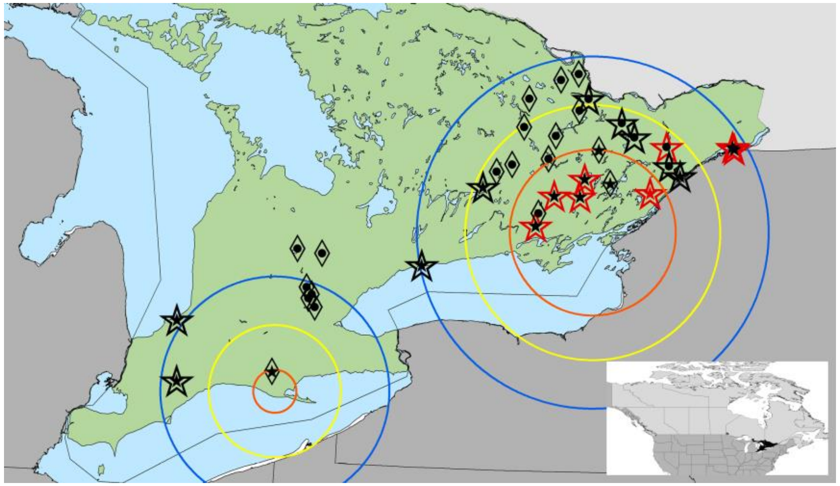




Ripoche et al. in prep

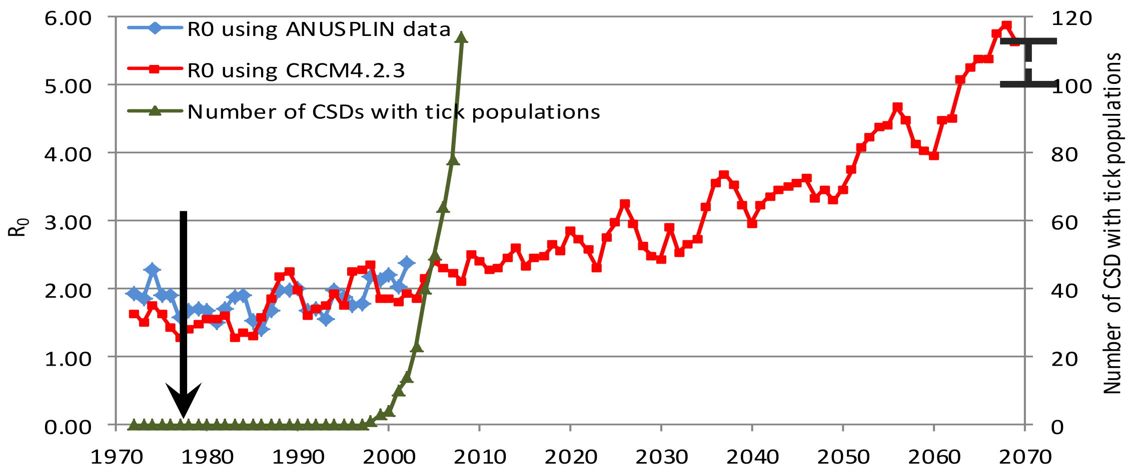


<u>Ontario</u> 2016 versus 2014/15

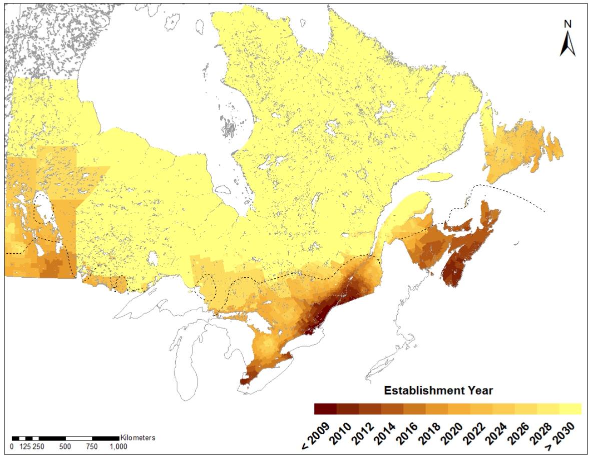


Clow et al. Plos One 2018

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



Leighton et al J App Ecol 2012

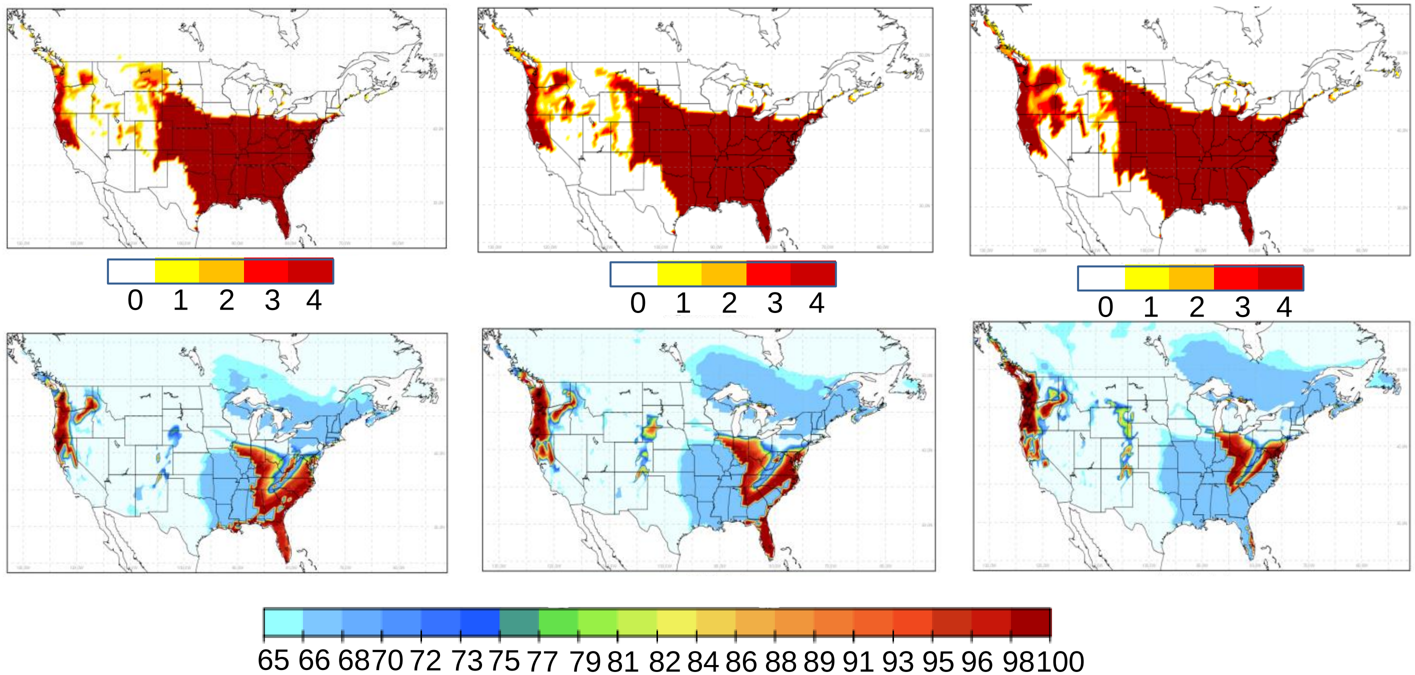
“There has been an increasing number of cases of Lyme disease in Canada, and Lyme disease vectors are spreading along climate-determined trajectories” (Koffi et al., 2012; Leighton et al., 2012). UN-IPCC AR-5

Risk assessments: chikungunya and zika vector *Ae. albopictus*

Climatic indicator | 2011-2040 RCP4.5 | 2041-2070 RCP4.5 | 2041-2070 RCP8.5

Overwintering + annual mean temperature

Jan temp + summer temp + annual rainfall

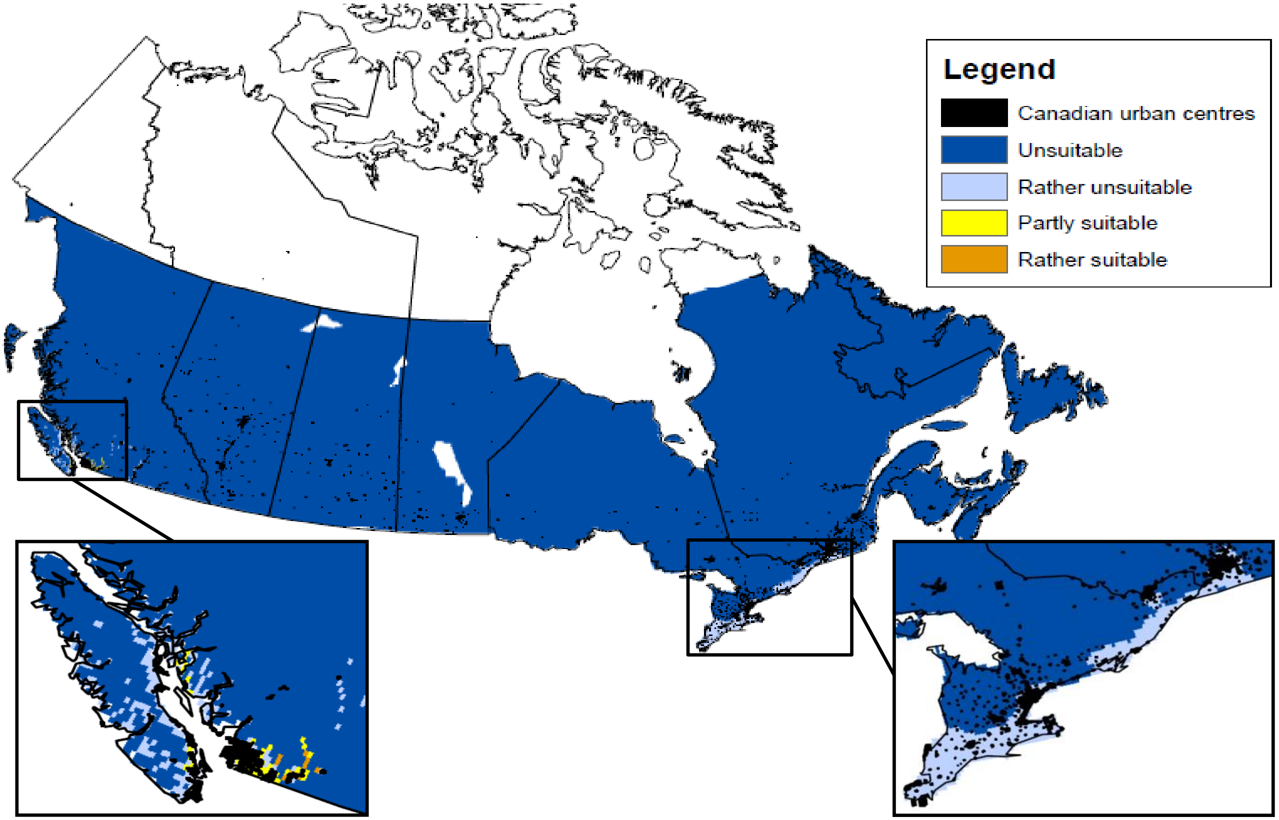


Ogden et al. 2014 Parasites & Vectors

Without validation

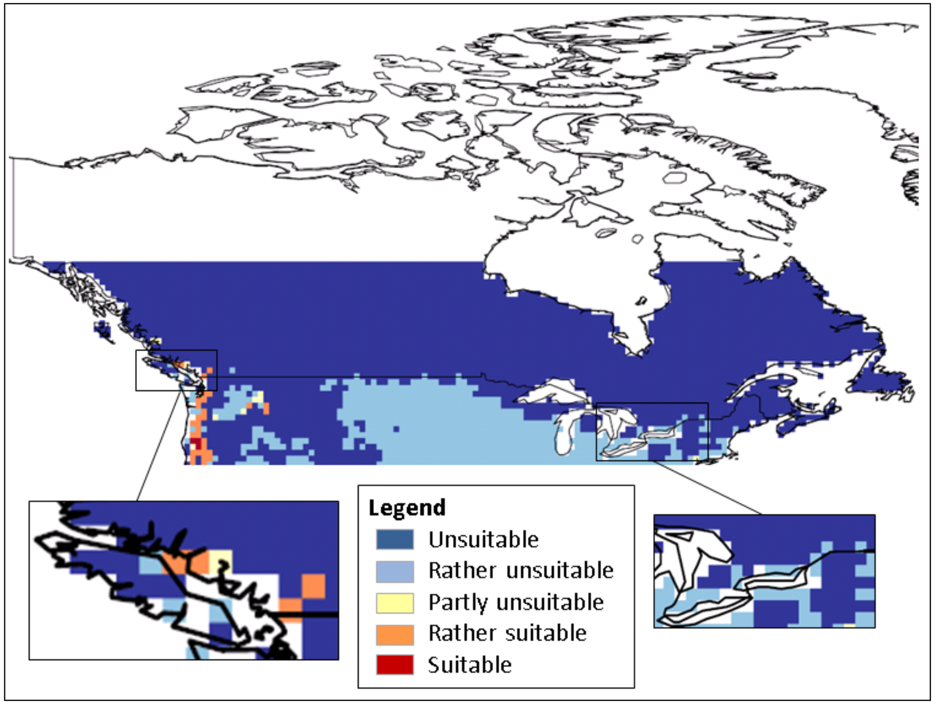
Model based risk assessment for CHIKV and ZIKV transmission in Canada

Current climate

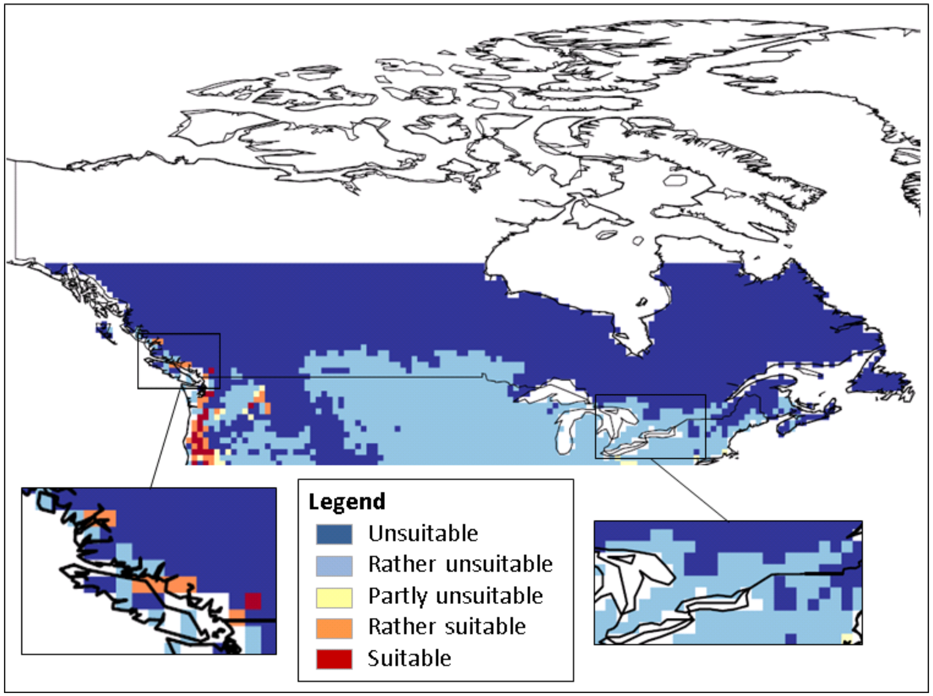


Future projections

Near future (to 2040)



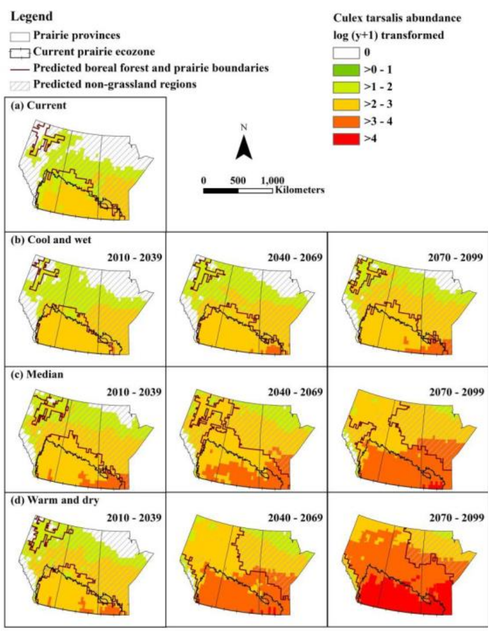
Far future (2041 - 2070)

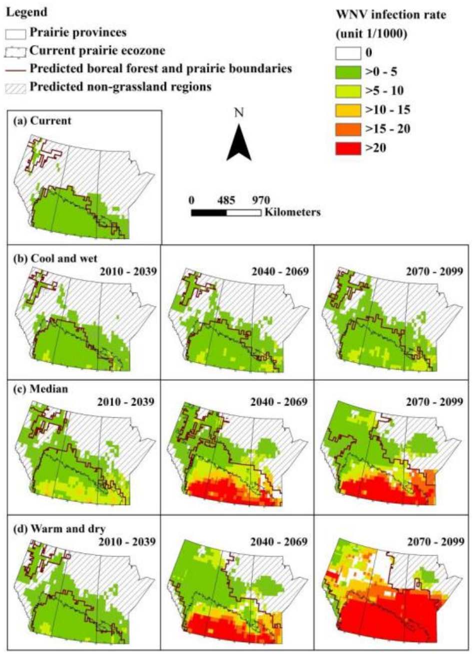


Ng et al. 2017 EHP

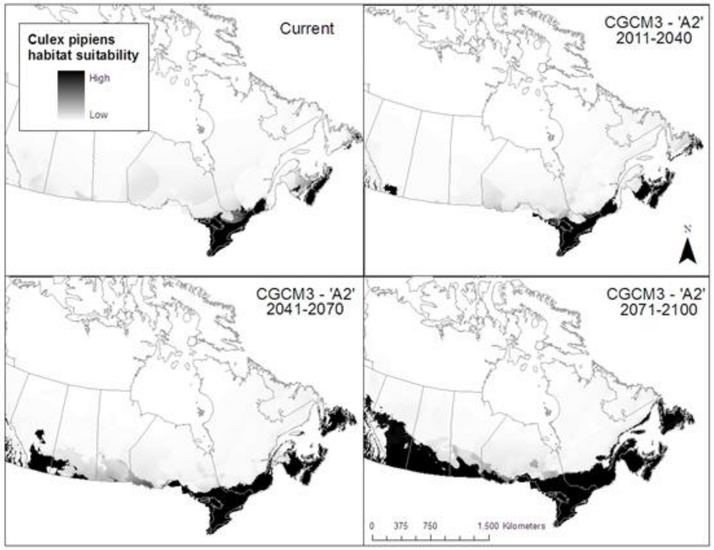
Risk assessments: WNV and its vectors *Culex pipiens & Cx. tarsalis*

WNV transmission & *Cx. tarsalis*:
Chen et al. Int. J. Environ. Res.
Public Health 2013





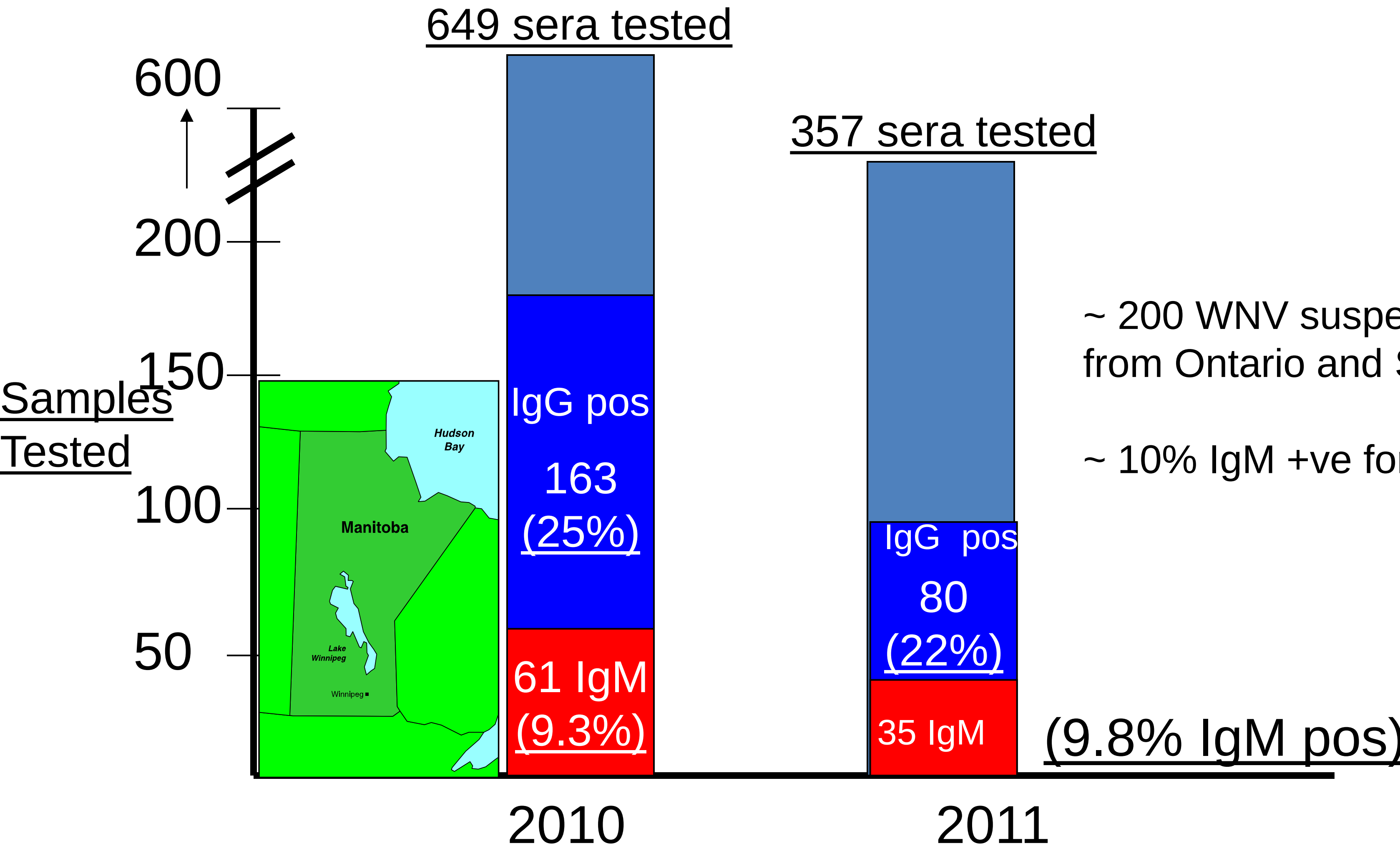
Cx. pipiens:
Hongoh et al., J App Geogr 2012



With validation

Without validation

Testing of suspect West Nile Virus negatives For California Serogroup virus antibody

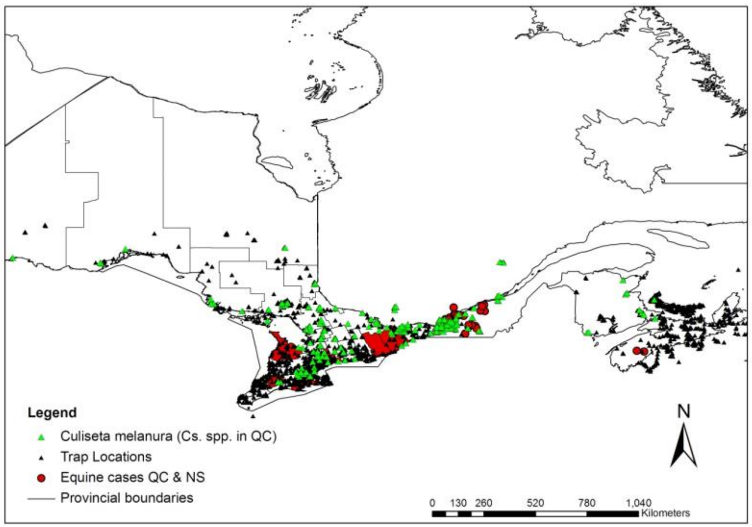


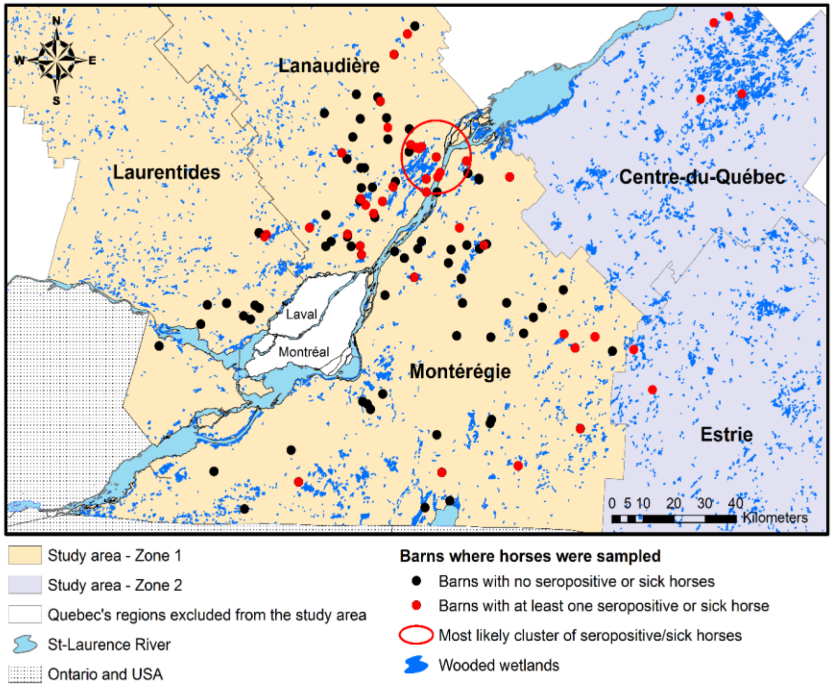
~ 200 WNV suspects tested from Ontario and Sask

~ 10% IgM +ve for JC /SSH

Emergence of EEE in eastern Canada

Reported observations of Culiseta melanura and equine cases of EEE from 2002 to 2008



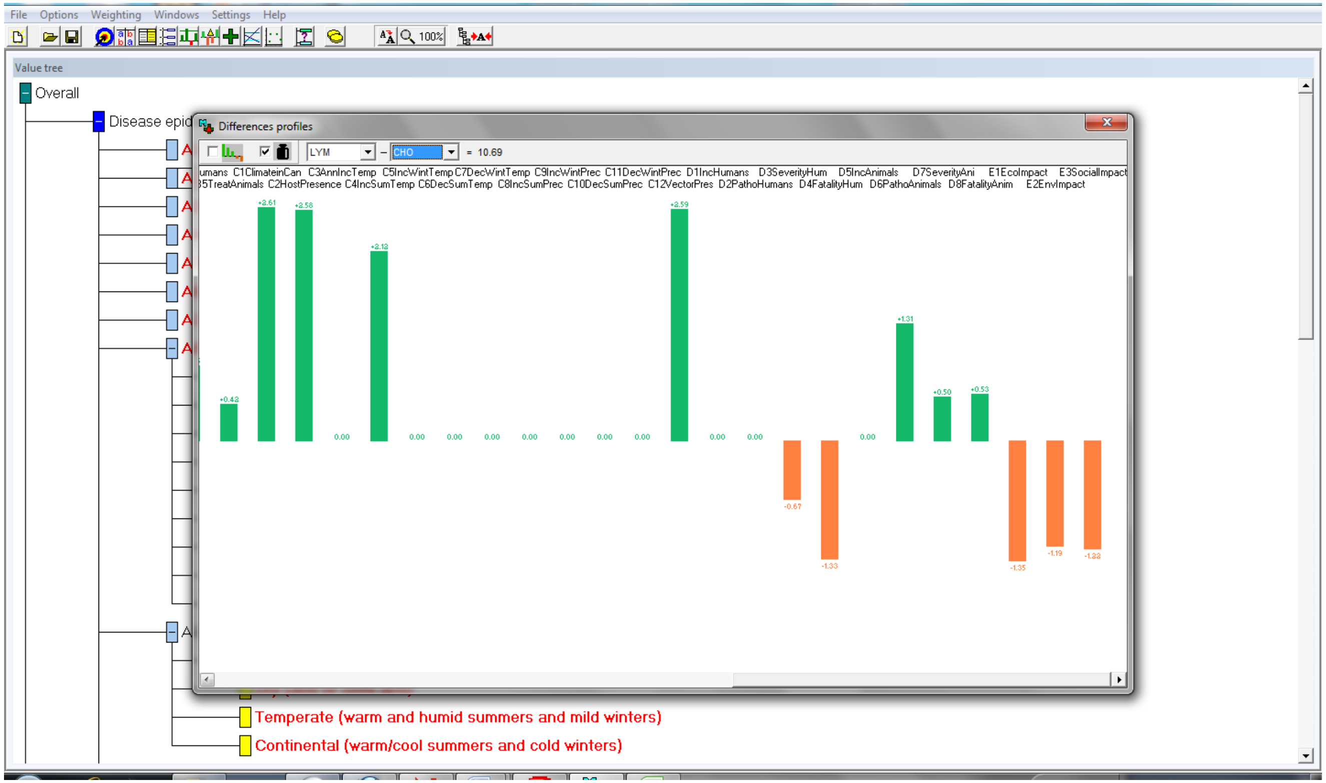


Rocheleau et al. 2017 Epidemiol Infect

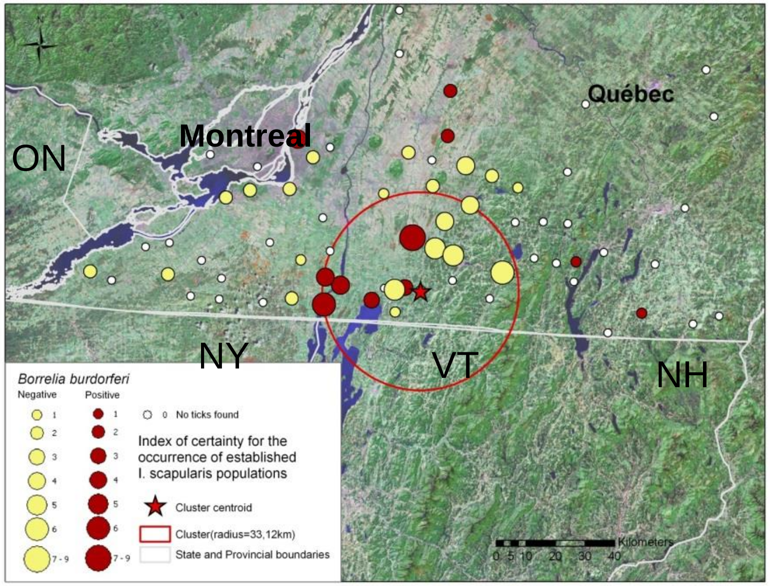
PUBLIC HEALTH TOOLS

Public health tools: prioritisation of VBDs

MCDA developed for prioritisation of climate sensitive zoonoses (Cox et al., 2012, 2013 PloS One)…being modified for our own internal processes

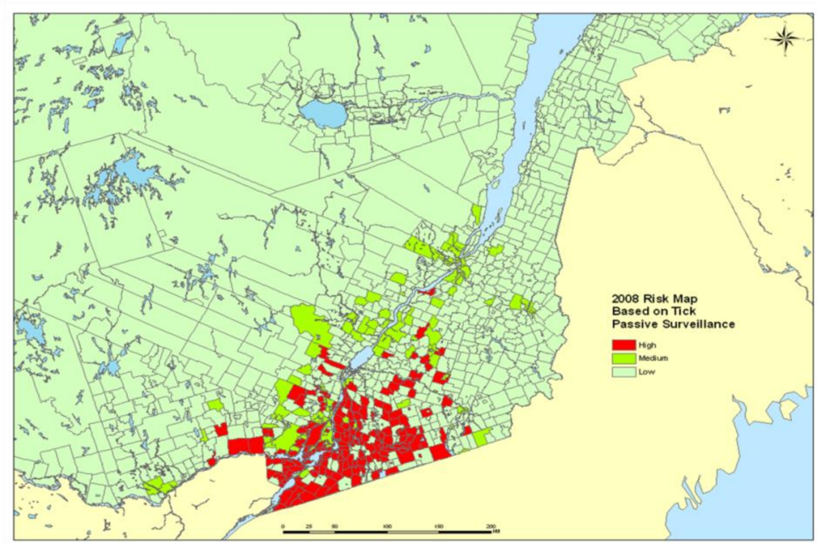


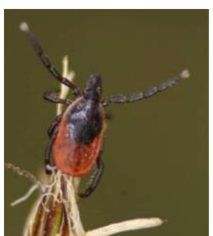
Public health tools: Tick surveillance and analysis methods

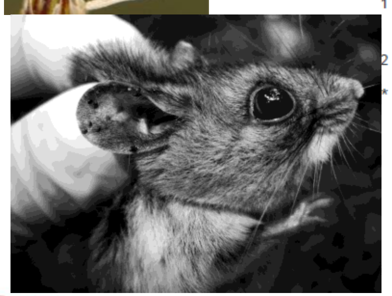


Ogden et al., 2010 EHP

Koffi et al., 2012 J Med Entomol







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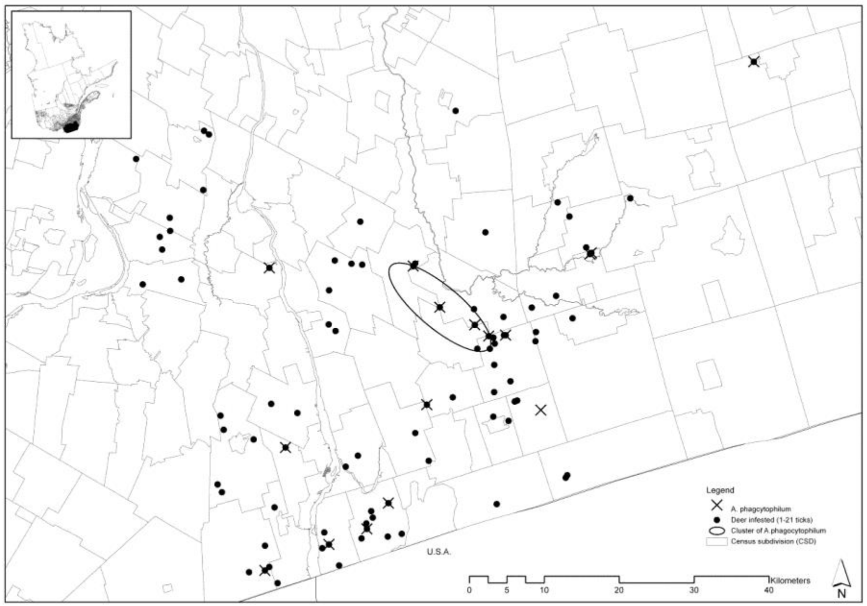
Assessment of a screening test to identify Lyme disease risk

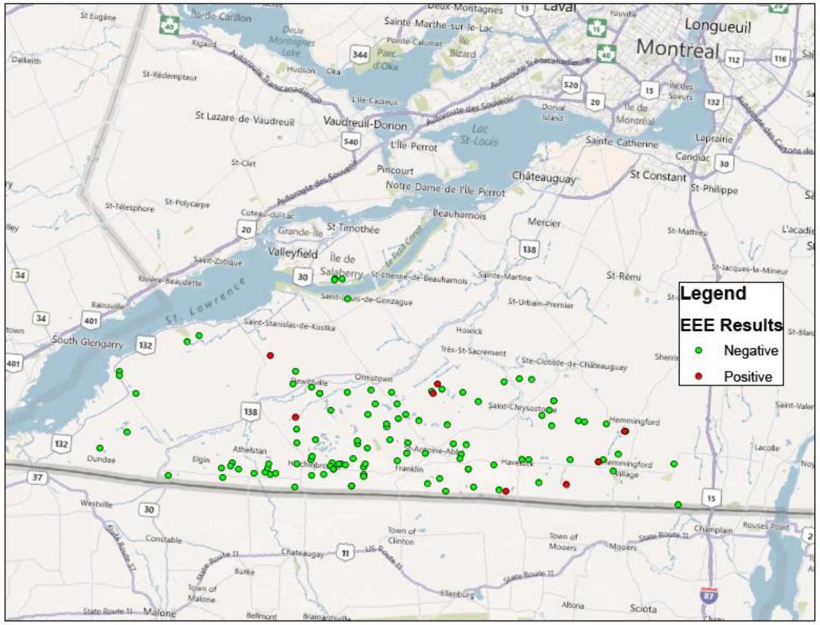
Ogden NH[1*], Koffi, JK[1], Lindsay LR[2]

[1] Centre for Food-borne, Environmental and Zoonotic Infectious Diseases, Public Health Agency of Canada, Saint-Hyacinthe, Quebec
[2] National Microbiology Laboratory, Public Health Agency of Canada, Winnipeg, Manitoba
* Corresponding author: nicholas.ogden@phac-aspc.gc.ca

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

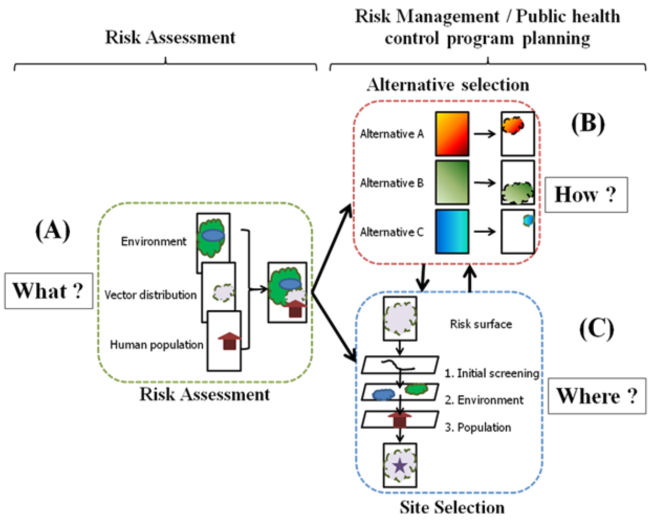


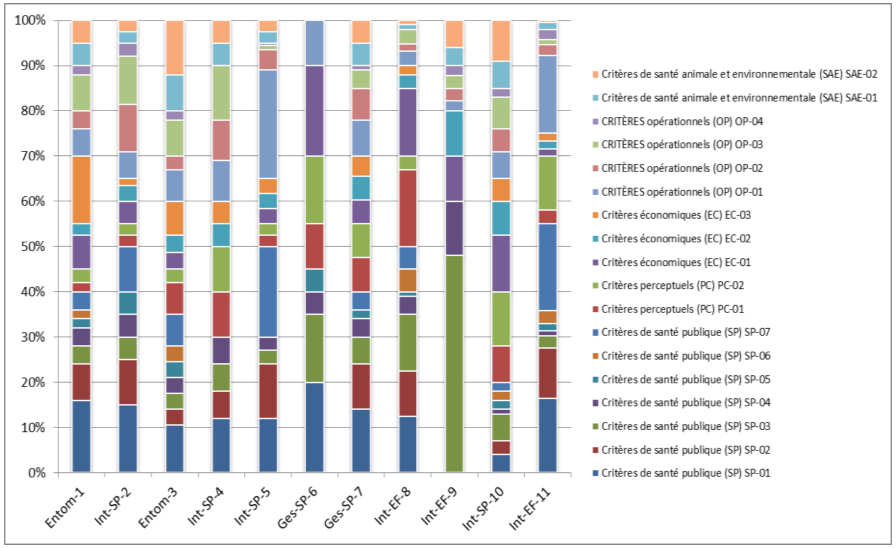
Arboviruses (EEE, WNV, CSGV)
Rocheleau et al. 2017 Epidem Infect

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

PLOS | ONE

RESEARCH ARTICLE

The Accuracy of Diagnostic Tests for Lyme Disease in Humans, A Systematic Review and Meta-Analysis of North American Research

Lisa A. Waddell[1☯*], Judy Greig[1☯], Mariola Mascarenhas[1☯], Shannon Harding[1☯], Robbin Lindsay[2‡], Nicholas Ogden[3‡]

Corrin et al. Tropical Medicine and Health (2017) 45:21
DOI 10.1186/s41182-017-0061-x

Tropical Medicine and Health

REVIEW Open Access

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

PLOS | ONE

RESEARCH ARTICLE

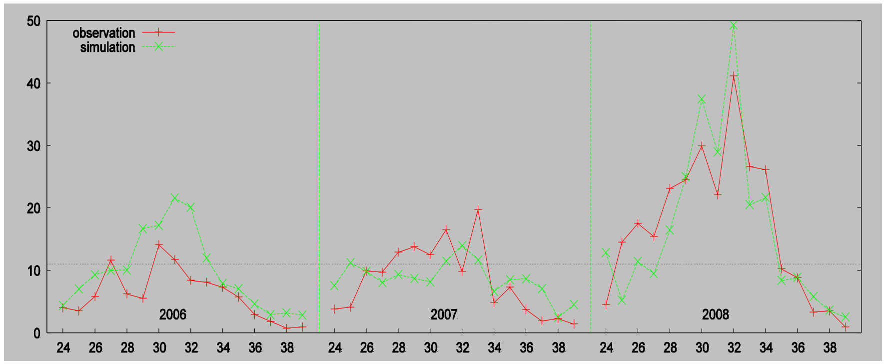
Scoping Review of the Zika Virus Literature

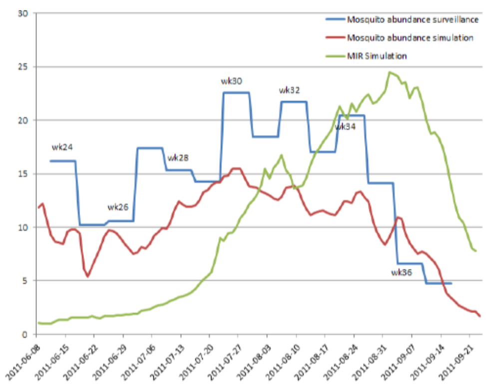
Lisa A. Waddell[1,2☯*], Judy D. Greig[1☯]

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

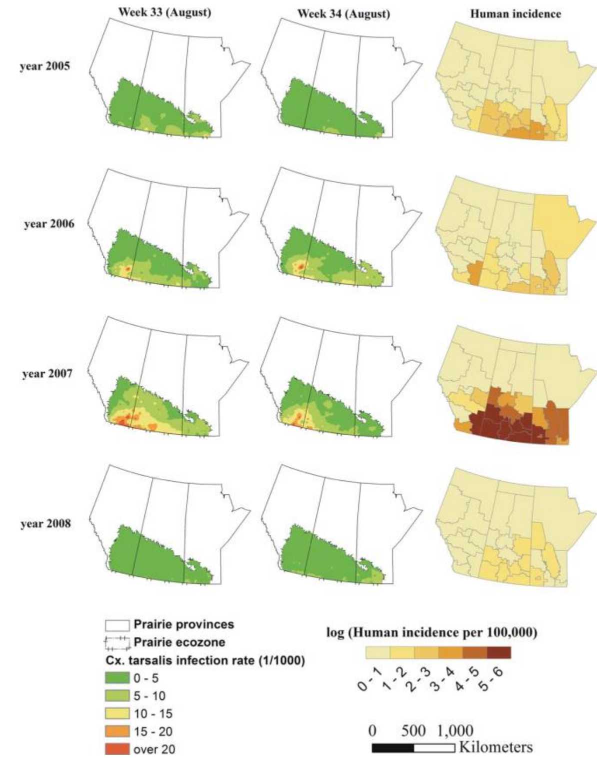
Forecasting WNv risk in the east:
Wang et al. 2011 J Med Entomol





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