Climate Change and Changing Patterns of Infectious Diseases

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Council of State and Territorial Epidemiologists
Annual Meeting
Omaha, Nebraska
June 6, 2012
Outline

• Climate change:
  – Concepts, trends and projections.

• Ecology, climate change and infectious diseases:
  – Vectorborne diseases.
    • Lyme.
    • West Nile.
  – Water- and foodborne pathogens.
  – [Not covered: influenza, nosocomial pathogens, endemic mycoses]

• Mitigation and vulnerability.
Greenhouse Gases (CO$_2$ and CH$_4$)

Concentrations of Greenhouse Gases from 0 to 2005

- Carbon Dioxide (CO$_2$)
- Methane (CH$_4$)
- Nitrous Oxide (N$_2$O)

(IPCC, 4th Assessment Report, 2007)
Relative Carbon Emissions

Source: worldmapper.com
Carbon Emissions per Capita vs. Per Capita GDP (2008)

Source: gapminder.com
Hard Choices

http://www.doonesbury.com/strip
• Accelerating pace of global warming (IPCC, 4\textsuperscript{th} Assessment Report, 2007)
Anthropogenic Greenhouse Gases

(IPCC, 4th Assessment Report, 2007)
Projections on Climate Change in North America

- Intergovernmental Panel on Climate Change (IPCC) 4th Assessment, 2007
  - Increased temperatures
  - Increased rainfall
  - Increased drought & wildfire
  - Increased frequency of “extreme” weather events
Already a Reality

Muir Glacier, Alaska, August 31, 2004, photo by B.F. Molnia

[Source: Lukaj Bogotaj, IPCC Pre-Meeting, Warsaw, October 2, 2010]
Disaster Frequency and Climate Change

There were 7 Significant Natural Catastrophes in the United States in 2009.

Source: Frank Nutter, Institute of Medicine panel on IEQ and Climate Change, June 7, 2010
Impact on Ecosystems

• **Ecosystem**: complex biological systems with living and non-living components.

• **Physical impact on ecosystems**: changing temperatures, water availability, ocean pH (via CO$_2$) and frequency of extreme events (fires, floods, extreme rainfall) stresses living components of environment.
Health Effects of Climate Change

- **Direct consequences**
  - Heat-related mortality.
  - Injuries (e.g., due to hurricanes, tornadoes and fires).
  - Displacement of populations (coastal flooding, desertification).

- **Indirect consequences**
  - Changes in the incidence and distribution of infectious diseases.
  - More complex causal pathways: enhanced infectious disease transmission due to displacement of populations.
Potential Impacts on Infectious Disease

- **Vector-borne disease**: changing ecosystems, ranges of amplifying hosts and insect vectors.
- **Diseases with environmental reservoirs**: Effects on food, water sources; “innoculation” via extreme weather events (e.g., melioidosis).
- **Communicable diseases (esp. respiratory pathogens)**: perturbations of seasonal patterns of transmission (environmental change); mass movement and crowding of populations via social disruption.
Vector-borne Disease
Prolonged Transmission Cycle

Current scenario

Warming scenario

Onset of spring temperatures
Eggs laid
WNV amplification in vector population
WNV infections in humans
Vectors die-off

Larval development
Figure 6. Life cycle of *Ixodes ricinus*. Hosts are listed in boxes; humans are potential hosts.

Model-derived temperature limits for *Ixodes scapularis* establishment in Canada (modified from Ogden et al., 2006)
1st reporting of Canadian human granulocytic anaplasmosis

Investigations conducted in Calgary, Alberta...have identified the 1st Canadian reported case of human granulocytic anaplasmosis (HGA) that is thought to have been acquired locally. An 82-year-old man was admitted to a local hospital with fever and progressive confusion...A fully engorged *Ixodes* tick was identified on the patient during his 2nd day of hospitalization. Laboratory findings revealed leukopenia...thrombocytopenia, and increased liver enzymes...Peripheral blood smears revealed intracytoplasmic inclusions within granulocytes consistent with morulae...A whole blood PCR confirmed the presence of *Anaplasma phagocytophilum*. With the addition of doxycycline to his treatment regimen the patient made a full recovery. **He had not traveled outside of the city of Calgary in many years.** His tick(s) were thought to have been acquired during repeated forays into local wooded recreational areas.
Lyme Disease Risk Quartiles, 1993-2007

Not shown: Alaska (0.34) and Hawaii (0.01).

[A. Tuite and D. Fisman, International Meeting on Emerging Diseases, 2009]

[A. Tuite and D. Fisman, International Meeting on Emerging Diseases, 2009]
Changes in Lyme Disease Risk in U.S., 1993 to 2007

Not shown: Alaska (IRR 1.28, 95% CI 1.15 to 1.42) and Hawaii (IRR 0.60, 95% CI 0.28 to 1.23)

[A. Tuite and D. Fisman, International Meeting on Emerging Diseases, 2009]
[A. Tuite and D. Fisman, International Meeting on Emerging Diseases, 2009]
West Nile Virus Infection

[J. Soverow et al., Environmental Health Perspectives, 2009]
Supplementary Figure: Schematic diagram of control selection strategy for case-crossover study. Each row represents a 3-week time block. Hazard and control periods (matched by day-of-week) are selected from the 3-week time block, resulting in random directionality of control selection.
El Niño Southern Oscillation: A Useful Model?

• Periodic thermal inversion in Pacific Ocean.
• Irregularly timed, ENSO effects:
  – Extreme weather events, heavy precipitation, elevated temperatures.
• Natural experiment that provides insight into future dimensions of climate change?
  – Relatively rare, so may need to evaluate indices, rather than “El Niño years”.
The Physical Environment and Disease Transmission
Water- and Foodborne Diseases

- An important source of morbidity in North America
  - Viral, bacterial and protozoan agents of gastroenteritis (e.g. *Salmonella* and *Shigella* species and toxin-elaborating *E-coli*).
    - Marked summertime (bacterial and protozoan pathogens) and wintertime (norovirus, rotavirus) seasonality.
  - Pneumonic pathogens (e.g. *Legionella* species)

- Large waterborne disease outbreaks have been linked to extreme precipitation events despite sophisticated water treatment systems (Charron et al., 2004; MacKenzie et al., 1994)
Association between extreme precipitation and waterborne disease outbreaks (modified from Auld et al., 2004)
Hurricane Katrina

[Source: U.S. CDC, MMWR September 23, 2005: 54(37);928-931. Available via the Internet at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5437a5.htm.]
Innoculation and Environmentally Abundant Pathogens

• Strength and frequency of extreme weather events (tornados, hurricanes, cyclones) projected to increase.
  – Generation of aerosols, inoculation via air- or waterborne debris.

• Severity of respiratory infection caused by *B. pseudomallei* increased following monsoon rains in northern Australia [Currie and Jacups, EID 2001].

• Infectious sequelae of South Asian tsunami in 2004: *Clostridial* infections, atypical *mycobacterial* infections of skin and soft tissues, *MDR GNR*. 
Response of pathogen growth rate to annual temperature and 1.5 degree average warming

Legionellosis, Philadelphia


[Observed vs. Expected cases per month]

[Date range from Jan-95 to Jan-03]

Summary IRR for legionellosis 6–10 days after rainfall = 2.48 (95% CI 1.30-3.12).

Summary IRR for legionellosis per % increase in RH 6–10 days prior to case occurrence 1.076 (95% CI, 1.048–1.106).
Campylobacteriosis, Philadelphia 1993-2007

Predictors: Increasing temperature and humidity. Decreasing river temperatures at 0-4 week lags.

[White A.N.J., et al., EcoHealth 2009]
Campylobacteriosis and Flies

Mitigation and Implications for Vulnerable Populations
Mitigation: The Texas—Mexico Dengue Gap

<table>
<thead>
<tr>
<th>Variable</th>
<th>Adjusted odds ratio</th>
<th>p value</th>
<th>95% Confidence interval</th>
<th>Deff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income ≤$100</td>
<td>2.59</td>
<td>0.000</td>
<td>1.58–4.26</td>
<td>0.92</td>
</tr>
<tr>
<td>Missing income</td>
<td>0.90</td>
<td>0.679</td>
<td>0.54–1.50</td>
<td>0.83</td>
</tr>
<tr>
<td>Street drainage</td>
<td>0.57</td>
<td>0.009</td>
<td>0.37–0.87</td>
<td>1.07</td>
</tr>
<tr>
<td>Larval habitat</td>
<td>2.35</td>
<td>0.008</td>
<td>1.26–4.41</td>
<td>1.00</td>
</tr>
<tr>
<td>Air-conditioning</td>
<td>0.58</td>
<td>0.014</td>
<td>0.38–0.89</td>
<td>1.04</td>
</tr>
<tr>
<td>Intact screens</td>
<td>1.35</td>
<td>0.111</td>
<td>0.93–1.95</td>
<td>0.90</td>
</tr>
<tr>
<td>Store water</td>
<td>1.62</td>
<td>0.079</td>
<td>0.95–2.76</td>
<td>1.19</td>
</tr>
<tr>
<td>Aedes aegypti</td>
<td>0.84</td>
<td>0.476</td>
<td>0.53–1.35</td>
<td>1.05</td>
</tr>
<tr>
<td>Cross border, 3 mo</td>
<td>0.90</td>
<td>0.581</td>
<td>0.62–1.31</td>
<td>0.93</td>
</tr>
<tr>
<td>People/household</td>
<td>1.06</td>
<td>0.300</td>
<td>0.95–1.19</td>
<td>1.31</td>
</tr>
</tbody>
</table>

*Missing data in independent variables (n = 22) did not significantly change prevalence of recent or past dengue infection (p > 0.10) in the remaining 578 observations used in subsequent models. Deff, design effect, the ratio of variance between the survey design and simple random sampling.

Brunkard JM et al., Emerging Infectious Diseases 2007.
Vulnerability and Climate Change

<table>
<thead>
<tr>
<th>Health Outcome</th>
<th>Vulnerable Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Stress</td>
<td>Elderly, chronic medical conditions, infants and children, pregnant women, urban and rural poor, outdoor workers</td>
</tr>
<tr>
<td>Air Pollution Effects</td>
<td>Children, pre-existing heart or lung disease, diabetes, athletes, outdoor workers</td>
</tr>
<tr>
<td>Extreme Weather Events</td>
<td>Poor, pregnant women, chronic medical conditions, mobility and cognitive constraints</td>
</tr>
<tr>
<td>Water- and Foodborne Illness</td>
<td>Immunocompromised, elderly, infants;</td>
</tr>
<tr>
<td>Vectorborne Illness</td>
<td>Children, pregnant women, outdoor workers</td>
</tr>
</tbody>
</table>

Source: Dr. John Balbus, Institute of Medicine panel on IAQ and Climate Change, Washington, DC, June 7, 2010
Heat Stress and Age

Summer 2003 London heatwave: 616 deaths (42% increase in mortality)

Conclusions

- **Global climate change**: major implications for human health.
- Impacts on **ecosystems** will change distribution and burden of vector-borne infectious diseases, including bacterial diseases. *Changes in epidemiology may already be underway?*
- **Mitigation**: impact likely to be borne principally by already-vulnerable individuals and groups.
Conclusions (2)

- **Surveillance**: Cornerstone of public health response.
  - Without measurement “flying blind”.
  - Canada: Lyme nationally notifiable only in 2009.
  - Other diseases with potential climate links (echinococcosis, blastomycosis) not reportable in US or Canada.
Acknowledgements

• **Collaborators:** Ashleigh R. Tuite (University of Toronto), Dr. Amy L. Greer (PHAC), Dr. Fran Jamieson (OAHPP), Alex White (University of Toronto), Laura M. Kinlin (Dalhousie University), Dr. Caroline Johnson (PDPH), Dr. Stefan Kuster (University of Zurich), Dr. Jeff Kwong (ICES), Dr. Allison McGeer (Mt. Sinai), Dr. Victoria Ng (University of Guelph), Marija Vasilevska (University of Toronto).

• **Funders:**
  – Ontario Early Researcher Award Program
  – U.S. National Institute of Allergy and Infectious Diseases (R21-AI065826)
  – Canadian Institutes for Health Research