The Impact of Global Warming on Vector-borne Diseases

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Faculty Disclosure

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“Nothing to disclose”
The Re-Emergence of Vector-Borne Infectious Diseases: The Role of Global Climate change

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The Global Emergence/Re-Emergence of Vector-Borne Infectious Diseases: The Role of Climate Change

- Introduction
- Effect of climate/weather on VBD
- Examples of emergent vector-borne diseases
- Factors responsible for the resurgence
- Conclusions
Infectious Disease Mortality in the United States, 1900 to 1990

Source: Armstrong et al., JAMA; 1999
The Global Threat of Infectious Diseases

Emerging and re-emerging diseases

Adapted from Morens, Folkers, Fauci 2004 Nature 430; 242-9
Global Re-Emergence of Epidemic Vector-Borne Infectious Diseases

• Emergence of Newly Recognized Diseases

• Expanding Geographic Distribution

• Increased Epidemic Activity
QUESTIONs?

• Why have we seen such a dramatic increase in epidemic vector-borne infectious diseases?
• What are the causes of epidemics?
• Why do epidemics differ in severity?
Scientists Predict Global Warming Will Lead to Spread of Disease


Dengue fever warning for Thailand

Deadly by the Dozen: 12 Diseases Climate Change May Worsen

Warming Increases Malaria, Dengue Fever Threat,

Climate change will fuel dengue - WHO exec

SOUTH AMERICA: Climate Change Fuels Spread of Dengue Fever

An exotic blend Dengue Fever is ready to spread across the country

Another death in dengue fever

Asian mosquito ‘could bring tropical diseases to Britain’, The Independent, 2013

Chikungunya disease in NYC? Warming could make it happen

Virus causes severe joint pain, is spread by two mosquito species; NBC News

Climate change, globalization, and other drivers have made Europe a “hot spot” for emerging infectious diseases, which calls for changes in monitoring systems

27 APRIL 2012 VOL 336 SCIENCE.
“Fueled by climate change, dengue fever is on the rise again throughout the developing world, particularly in Latin America”.

State of knowledge at IPCC 4AR (2007)

- Global warming is unequivocal
- Projected trends in climate change-related exposures of importance to human health will: affect millions of persons, through
  - increase in malnutrition
  - increase the number of people suffering from death, disease and injury from extreme weather events
  - continue to change the range of infectious disease vectors
  - have mixed effects on malaria
  - increase the burden of diarrhoeal diseases
  - increase the frequency of cardio-respiratory diseases
  - increase the number of people at risk of dengue

Data supporting many of these conclusions are questionable
Warming is Unequivocal

Rising atmospheric temperature
Rising sea level
Reductions in North Hemisphere snow cover

Extreme weather events are more frequent

Adapted from IPCC Summary for Policymakers: WG I (2007).
Dengue/Dengue Hemorrhagic Fever, Average Annual Number of Cases Reported to WHO, 1955-2003
Common Assumptions, Statements based on IPCC Report, 2007

Arthropod-borne diseases…….

• Moving to temperate zones
• Moving to higher altitudes
• Increased transmission

Courtesy, P Reiter
Global Warming?

Falling off the scale
Change in global mean temperature, °C

- Actual
- Computer models
  - 5-95%*
  - 25-75%*

Source: Ed Hawkins, University of Reading; CMIP5 model dataset

*Confidence interval
What do We Know About Global Climate Change and Infectious Diseases?

- Global warming has been occurring
  - Probably resulting from both natural and anthropogenic causes
  - Stable temperatures past 10 years
- Many infectious diseases are climate sensitive
  - Some have been influenced by global warming
  - Positive and negative effects
- Likely both adverse and beneficial effects on human health
Links between climate/weather and vector-borne disease

Distal causes
- Temperature
- Humidity
- Precipitation

... wind

Proximal causes
- Development of the vector
- Longevity of the vector
- Development of the pathogen
- Spatial distribution and abundance of the vertebrate host
- Habitat of the vector

Infection hazards
- Vector infection & infectivity rates
- Vector abundance
- Vector biting rates on humans

Health outcome
- Infection incidence
- Clinical illness
- Mortality

Vulnerability: immunity to infection

Adapted from Gubler, (2001)
How will Climate Change Influence Ecology of Vector-Borne Diseases?

- Variable Weather Patterns
- Variable Temperature
- Variable Water Abundance
- Changing Vegetation Patterns
- Changing Vertebrate Host Species
- Changing Vertebrate Host Behavior
Influence of Climate Change on Vector-Borne Diseases

• Increased Temperature
  ▪ Higher transmission potential
    • Decreased vector generation time
    • Increased vector population growth rate
    • Decreased extrinsic incubation period
    • Increased transmission period
  ▪ Lower transmission potential
    • Decreased vector survival time
    • Lower vector-vertebrate host contact rate
    • Inhibition of parasite growth
Influence of Climate Change on Vector-Borne Diseases

• Increased Water Abundance
  ▪ Higher transmission potential
    • Increased vector population densities
    • Increased vector survival rates
      – Lower temperature
      – Higher humidity
  ▪ Lower transmission potential
    • Decreased vector population densities
      – Flooding
    • Decreased vector-vertebrate host contact
High Profile Epidemic Infectious Diseases Linked to Climate Change in Recent Years

- Lyme disease
- Malaria
- Dengue
- Chikungunya
- West Nile
- Tick-borne encephalitis
- Bluetongue
- Nipah encephalitis
Reported Lyme Disease Cases by Year
United States, 1982-2002
POPULATIONS OF *Ixodes scapularis* ARE DEPENDENT UPON WHITE-TAILED DEER

Courtesy, D. Fish
REFORESTATION OF THE NORTHEAST

1900
DEER ABSENT OR RARE

1970
DEER ABUNDANT

Courtesy, D Fish
SUBURBANIZATION

Courtesy, D Fish
Has host availability changed, driven by environmental changes or human behaviour?

Lyme neuroborreliosis in Denmark correlated with roe deer density temporally and spatially

$R^2 = 0.834$

Annual Lyme neuroborreliosis cases
Deer density per 1000ha

$R^2 = 0.586$

Tick density at 35 sites 1996

$R^2 = 0.723$

Lyme cases per county 1993-95

Future climate change and malaria

Malaria kills 0.5-0.7 million people every year, 95% in Africa.

Modeling studies have suggested that global warming might change transmission – but They have been flawed.

(Figure from Tanser et al, Lancet, 2003)
Most of the malaria burden is from deaths in young children

Deaths (thousands)

- Africa
- Rest of the world

Source: Africa Malaria Report 2003, Figure 1.3
"In the past 15 years...

‘Malaria transmission in highland regions due to
‘Global Warming?’

Courtesy, P Reiter
Transmission of malaria at altitude: then and now

Highland areas are < 2% of land area, and many are too arid for transmission

**1880 - 1945**

**Recent**

Latitude

1. USA
2. India
3. China
4. Ethiopia
5. Colombia
6. Kenya
7. Ecuador
8. Peru
9. Rwanda
10. Tanzania
11. Papua NG
12. Madagascar
13. Bolivia
14. Chile
15. Argentina
16. Mexico
17. Costa Rica

Longitude

18. Mexico

Altitude (m)

0 500 1000 1500 2000 2500 3000

North

South

Latitude

Equator

Courtesy P Reiter

30
The 20th Century Pandemic of Dengue

Expanding geographic Distribution

Increased epidemic activity

Hyperendemicity

Emergence of DHF

Average annual number of DF/DHF cases reported to WHO, 1955-2008

Source: DengueNet
2008 data provisional
Dengue and Hemorrhagic Fever
A Potential Threat to Public Health in the United States

David M. Morens, MD
Anthony S. Fauci, MD

Trends, most notably in Thailand, have greatly reduced case-fatality rates. The

32

2001-02

DEN-1

DEN-2

DEN-3

DEN-4

Endemic/epidemic

Epidemic Dengue in the US 1900-2011
## Autochthonous Dengue in the United States

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<td>2011</td>
<td>Hawaii</td>
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</table>
Dengue/DHF Texas 2005

• 25 autochthonous cases
• 1st record of DHF
• 38% of population with dengue antibodies

MMWR 2007;56:785
Dengue at the Frontier, 1980-1999: Culture, Economy and Environment more important than temperature

Border states: 62,514 cases

Texas: 64 cases

A 1000-fold difference

Courtesy, P Reiter
Factors contributing to CHIK spread

- Mutation in the E1 envelope glycoprotein adapting CHIKV for more efficient infection of *Aedes albopictus* (Schuffenecker *et al.*, 2006; Tsetsarkin *et al.*, 2007; Vazeille *et al.*, 2007)
- Lack of CHIK-specific immunity in human populations
West Nile Virus in the Western Hemisphere
199 West Nile Virus Activity

4 States

62 Cases

National Center for Infectious Diseases
West Nile Virus Activity
Cumulative results for 1999 calendar year
200 West Nile Virus Activity
27 States
66 Cases

National Center for Infectious Diseases
West Nile Virus Activity
Cumulative results for 2001 calendar year
200 West Nile Virus Activity
44 States
4156 Cases

National Center for Infectious Diseases
West Nile Virus Activity
Data results for 2002 calendar year reported as of April 15, 2003
46 States
9862 Cases

200 West Nile Virus Activity

3 Non-Human WNV Activity
Red Human Disease Cases

National Center for Infectious Diseases

West Nile Virus Activity
Results for 2003 calendar year reported as of May 20, 2004
200
West Nile Virus Activity

4  Non-Human WNV Activity
Human Disease Cases

47 States
2535 Cases

National Center for Infectious Diseases
West Nile Virus Activity
Preliminary results for 2004 calendar year reported as of January 11, 2005
West Nile Virus Activity

200

5

Non-Human WNV Activity
Human Disease Cases

48 States
2819 Cases

National Center for Infectious Diseases
West Nile Virus Activity
Diagnostic results for 2005 calendar year reported as of January 3, 2006

CDC
Persistent Epidemic Transmission Foci Have Developed

200 West Nile Virus Activity
6 Non-Human WNV Activity
48 States
4219 Cases

West Nile Virus Activity
National Center for Infectious Diseases

West Nile Virus Activity results for 2006 calendar year reported as of Dec 15, 2006
West Nile Virus in the US

Culex tarsalis

Culex pipiens pipiens

Culex pipiens quinquefasciatus

Culex nigripalpus

1999
2000
2001
2002
2003
2004

Courtesy, W Tabachnick
Molecular Evolution of WN Virus Strains

Phylogenetic Tree of West Nile Viruses

Data: CDC
Has climate changed in the right place, at the right time and in the right way to account for the observed changes in tick-borne diseases?

Sweden: mean Spring temperature increased from 1989

Mean Spring temperature °C
March-May

after the increase in TBE incidence

A cause cannot occur after an effect!

Courtesy, S. Randolph
Have local socio-political effects caused altered human behavior/agriculture involving greater use of tick-infested habitats for work, food harvest and leisure activities?

'Re Emergence' of TBE coincided with independence from communist rule.

Recorded annual cases of TBE

Courtesy, S. Randolph
Blue Tongue Virus

Virus
Famille Reoviridae
Genre Orbivirus
24 sérotypes

Vector
Haematophagous fly of the genus Culicoides

Bloodmeal on a viraemic animal

Reservoir host
Blood of infected ovines (viraemia < 15d - max 30 d) and bovines (viraemia - max 100 d)

Bloodmeal on an uninfected animal

Courtesy, M Nathan
The 10 introductions of different BTV strains into north Africa & Europe since 1998

Courtesy, M Nathan
Introductions of BTV into Europe since 1998

- Italy
- Belgium
- The Netherlands
- Germany
- France
- Luxembourg
- Czech Republic
- Hungary
- Sweden
- Switzerland
- United Kingdom
Spread of BTV

*Initial focus*

- Passive movement of Vectors $\rightarrow$ 700 km
- Transport of infected animals

*New foci*

Courtesy, M Nathan
Although the hypothesis that global warming is responsible for the global re-emergence of vector-borne diseases is plausible, there are many other explanations that are just as plausible.

“Plausibility is not Proof”
Tabachnick, 2010
Why Have we Seen Such a Dramatic Increase in Epidemic Infectious Diseases

• Complacency, Lack of Political Will
• Policy Changes
• Changes in Public Health
• Changing Life Styles/Behavior
• Microbial Adaptation
• Technology
• Intent to Harm
• Climate Change
Why Have we Seen Such a Dramatic Increase in Epidemic Vector-Borne Infectious Diseases

Major Drivers

• Demographic Changes (Pop Growth)
  ▪ Environmental Change
    - Uncontrolled Urbanization
    - Agricultural/Land Use Practices
    - Deforestation
  ▪ Animal Husbandry

• Modern Transportation (Globalization)
  ▪ Increased Movement of People, Animals, Commodities and pathogens

• Lack of Effective Vector Control
Global population- 1950-2050

Estimated urban and rural population between 1950 and 2050
Urban growth in Asian and American Cities, 1950-2010

Mean population of Dhaka, Bangkok, Jakarta, Manila and Saigon.
Mean population of Rio de Janeiro, Sao Paulo, San Juan, Caracas and Guayaquil.
The global air network
Average annual number of global airline passengers by decade, 1950-2010

IATA 2010
Global Threat of Epidemic Infectious Diseases

• Disease and Trade-interwoven History
  ▪ 14th century, Europe discovers exotic goods from Asia

• Global Trade Flourishes
  ▪ 18th, 19, 20th centuries

• New Millennium
  ▪ Integrated global economic system with a transnational flow of capital, products, people, animals, knowledge, and pathogens
  ▪ Rapid spread of epidemic infectious disease from point of origin
Global distribution of dengue virus serotypes, 1970
Global distribution of dengue virus serotypes, 2013
Exotic Infectious Diseases That Have Recently Been Introduced to the US

- West Nile Fever
- Yellow Fever
- Mayaro Fever
- Dengue Fever
- Chikungunya
- SARS
- Influenza
- Lassa Fever
- Monkeypox
- CJD/BSE
- HIV/AIDS
- Cholera
- E. coli O157
- Leishmaniasis
- Chagas Disease
- Cyclospora
Live Animal Importation into the USA - 2002

- 47,000 mammals
  - 28 species of rodents
- 379,000 birds
- 2 million reptiles
  & Poisonous snakes
- 49 million amphibians
- 223 million fish

U.S. Fish & Wildlife Service Data
Exotic Mosquito Species Recently Introduced and Established in the United States

- *Aedes (Stegomyia) albopictus*
- *Aedes bahamensis*
- *Ochlerotatus (Aedes Finlaya) togoi*
- *Ochlerotatus (Aedes Finlaya) japonicus*
- *Culex biscayensis*
Urbanization
Agricultural, land use and animal husbandry changes/practices
Habitat alteration

Species’ Ecological-evolutionary Dynamics
*Opportunistic habitat expansion/ecological release*
- Vector (domestication)
- Feral vector/reservoir species
- Wildlife/reservoir transport/encroachment
- Human encroachment

Host-Pathogen Dynamics
*Emergence Processes of ‘Host-Parasite Biology’*
- Host switching (host novelty)
- Breaching of pathogen persistence thresholds
- Transmission amplification and genetic change (pathogen novelty)

Disease Emergence

Wilcox and Gubler, 2006
The Effect of Global Climate Change on the Emergence of Epidemic Vector-Borne Diseases

Conclusions

• Vector-borne infectious diseases are maintained in complex transmission cycles; there are a multitude of extrinsic and intrinsic factors that influence transmission dynamics
• Disease early warning systems cannot be based on temperature and weather/climate alone
• Effective disease detection and prevention must be based on an understanding of the disease ecology
The Effect of Global Climate Change on the Emergence of Epidemic Vector-Borne Diseases

Conclusions

• Economic, demographic, environmental, technological and societal changes are the principal drivers of the re-emergence of vector-borne infectious diseases
• The effects of climate variability are uncertain, and may be focal
• Reversing global warming will likely have little or no impact on emerging vector-borne diseases
• Any adverse effect of climate change on infectious diseases can be mitigated by developing good public health infrastructure and effective prevention strategies
There is no solid scientific evidence to date that global warming has been a major driving force of the 20th century re-emergence of vector-borne infectious diseases!
Global warming has become the ideal excuse for public health officials and policy makers to explain why we are having repeated epidemics of diseases that were once effectively controlled.
Adverse Effects of Climate Change on Human Health can be Mitigated

- Research
- Rebuild public health infrastructure
- Develop and implement effective prevention strategies