Global Climate Change and Mosquito-Borne Diseases

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Evidence for Global Climate Change

- World climate is in a warming phase that began in the early decades of 18th century (faster than any period in last 1000 years) (increase of 1.5°F over past 100 yrs.)
- Sea levels have risen ~ 2-3 mm per year since 1961
- Arctic sea ice has declined by 10% per decade
- Snow cover and glaciers have diminished in both hemispheres
- Accelerating worldwide hydrological cycle
  - Increasing the intensity, frequency, and duration of droughts, heavy precipitation events and flooding
- Predictions from United Nations Intergovernmental Panel on Climate Change (IPCC): in next 90 years
  - Global temperature will increase between 1.8 °C and 4.0 °C
  - Sea levels will rise between 18 and 59 cm (up to 2 ft.)
Observed Changes in North American Extreme Climate Events

- Warmer and fewer cold days and nights
- Hotter and more frequent hot days and nights
- More frequent heat waves and warm spells
- More frequent and intense heavy downpours and total rainfall in precipitation events
- Increases in area affected by drought
- More intense hurricanes
Mosquitoes, in their role as vectors, are critical components in the transmission cycle of many disease causing pathogens that affect hundreds of millions of people worldwide:

- Malaria
- Dengue
- Yellow Fever
- Japanese Encephalitis
- Chikungunya
- Rift Valley Fever
- Filariasis
- West Nile virus

Mosquitoes and the pathogens they transmit are directly impacted by changes in weather and climate:

- All vector-borne pathogens spend a part of their life cycle in cold-blooded arthropods and are subject to environmental factors
- Marginal changes in temperature, humidity and rainfall can have potentially large biological effects on disease transmission
Hypothesis:
Global warming will increase the incidence of mosquito-borne infectious diseases

Rationale:
Most mosquito-borne diseases, including Dengue, Malaria, and Yellow Fever occur in the tropics, are weather sensitive, and have distinct seasonal patterns

Therefore:
If warming heats up the globe, then these and other mosquito-borne diseases will expand into new regions and become more prevalent in areas where they already occur

However:
Climate change is only one of many factors affecting the incidence of mosquito-borne diseases

Socioeconomic factors – human activities that impact the local ecology are equally important and may have an equal or greater impact
Drivers for Changes in the Status of Mosquito-Borne Diseases

- Industrial & agricultural chemical pollution
- Land use, water storage, and irrigation
- Atmospheric composition
- Climate change
- Mosquito-Borne Diseases
- Urbanization with poverty
- Weather
- Invasive mosquitoes & pathogens
- Trade & human movement

Adapted from Sutherst, Clin. Microbiol. Rev. 2004
**Increased Temperature Effects on Mosquitoes**

- Can extend season when mosquitoes are active and transfer infectious agents for longer period of time
- Increase overwintering survival
- Shorten larval development time
- Increase adult feeding - females digest blood more quickly and feed more frequently
- Increase adult survival at higher latitudes

- Can extend distribution range of more tropical vector species
  - *Aedes aegypti*
  - *Aedes albopictus*

- Decrease survival of some species

- Increase capacity to produce more offspring
- Increase frequency of contact with humans or other hosts

Bring mosquito vectors into contact with new human populations
Extrinsic incubation period of pathogen is decreased in vector at higher temperatures

- The period of time from when a mosquito takes an infectious bloodmeal until it transmits the pathogen
- Pathogens inside the mosquito develop faster in heat, increasing transmission efficiency and the likelihood of the disease being spread
Mosquito feeds / acquires virus

Extrinsic incubation period

Viremia

Illness

Human #1

DAYS

12

20

Mosquito refeeds / acquires virus

Intrinsic incubation period

Viremia

Illness

Human #2

28
Infection of mosquito feeding on a viremic animal

Virus particles in blood
Digestion of blood
Spread of virus within midgut

Peritrophic Membrane

Semipermeable, non-cellular matrix composed of chitin and protein
Dissemination from the midgut into the hemocoel

- Fat body
- Salivary glands
- Nervous system
- Hemocoel
Virus replication in secondary tissues in body
Transmission of virus from mosquito to new host

Salivary glands
### Impact of Temperature on Pathogen Development in the Mosquito Vector

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Vector</th>
<th>Low Temp</th>
<th>High Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dengue</td>
<td>Dengue virus</td>
<td>Aedes aegypti</td>
<td>12 days at 30 °C</td>
<td>7 days at 32-35 °C</td>
</tr>
<tr>
<td>Malaria</td>
<td>Plasmodium vivax</td>
<td>Anopheles gambiae</td>
<td>18 days at 20 °C</td>
<td>7 days at 30 °C</td>
</tr>
<tr>
<td>Malaria</td>
<td>Plasmodium falciparum</td>
<td>Anopheles gambiae</td>
<td>23 days at 20 °C</td>
<td>9 days at 30 °C</td>
</tr>
<tr>
<td>West Nile virus</td>
<td>West Nile virus</td>
<td>Culex pipiens</td>
<td>15 days at 20 °C</td>
<td>5 days at 30 °C</td>
</tr>
<tr>
<td>West Nile virus</td>
<td>West Nile virus</td>
<td>Culex tarsalis</td>
<td>20 days at 20 °C</td>
<td>6 days at 30 °C</td>
</tr>
</tbody>
</table>
Temperature Effects on Pathogens

• Changes in the distribution and length of the transmission season
  – Sustained outbreaks of Malaria only occur where temperatures routinely exceed 14-15 °C (60 °F)
  – Yellow fever and Dengue fever only occur where temperatures rarely fall below 10 °C (50 °F)
  – Outbreaks of West Nile and St. Louis encephalitis viruses are associated with above average summer temperatures

• Decreased viral replication at high temperatures

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Vector</th>
<th>Min Temp</th>
<th>Max Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaria</td>
<td><em>P. falciparum</em></td>
<td>Anopheles</td>
<td>16-19 °C</td>
<td>33-39 °C</td>
</tr>
<tr>
<td>Malaria</td>
<td><em>P. vivax</em></td>
<td>Anopheles</td>
<td>14-15 °C</td>
<td>33-39 °C</td>
</tr>
<tr>
<td>Dengue</td>
<td>Dengue virus</td>
<td><em>Aedes</em></td>
<td>12 °C</td>
<td>Not known</td>
</tr>
</tbody>
</table>
**Increased Precipitation**

**Negative Impacts**

- Will increase the number and quality of larval breeding sites
- Epic rainfall events can synchronize mosquito host seeking and pathogen transmission
- Associated increase in humidity will increase mosquito survival

**Positive Impact**

- Excess rainfall or snow pack can eliminate larval habitat by flooding thus decreasing the mosquito population
Decreased Precipitation

Negative Impacts

• Low rainfall can create larval habitat by causing rivers to dry into “pools” that serve as production sites (dry season malaria)

• Decreased rain can increase container-breeding mosquitoes by forcing increased water storage

Positive Impact

• Will generally decrease number and quality of larval breeding sites
Few direct effects but some data indicate that humidity affects malarial parasite development in *Anopheles* mosquitoes.
Climate change may affect the incidence of mosquito-borne diseases through its effect on four principal characteristics of vector mosquito populations that relate to pathogen transmission:\(^1\)

- **Geographic and Temporal Distribution**: Range shifts in vector distribution that bring mosquito vectors into contact with new human populations
- **Population Density**: Changes in the population density of the mosquito vector that would result in increased frequency of contact with humans
- **Prevalence of Infection by Zoonotic Pathogens**: Changes in the prevalence of pathogen infection in the reservoir host or mosquito vector population that would increase the frequency of human contact with infected mosquito vectors
- **Pathogen Load**: Changes in pathogen load brought about by changes in the rates of pathogen reproduction, replication, or development in the vector mosquito

\(^1\text{Adapted from Mills et al. Environ Health Perspectives 118 (2010)}\)
• **Africa**: Increases in the incidence of malaria are strongly associated with higher temperatures and rainfall.

• **South America**: Strong association between El Nino and incidence of outbreaks.

• Climate modeling shows that global warming will likely enlarge the potential range of *Anopholes* vectors and thus can expect increased expansion of disease.
• **Africa**: Increase in incidence associated with increased humidity

• **Asia**: Many countries experienced high activity associated with 1998 El Nino

• Climate warming may increase area of land suitable *Aedes aegypti* and slight increase in temperature could result in epidemics

• Epidemics in the America's have been linked to the reestablishment of *Ae. aegypti*

• Key West, FL – outbreak in 2009

• 22 locally acquired cases in Florida in 2013
• Previously confined to central Africa but during the last century has expanded into more temperate regions

• **Africa:** 2004 epidemic in Kenya associated with unseasonably dry conditions and inadequate socioeconomic conditions
  
  – Unsafe domestic water storage
  
  – Shortened extrinsic incubation period in *Aedes aegypti*

• A single mutation in viral genome facilitated adaptation to *Aedes albopictus* played a major role in expansion from Africa in 2005

• Expansion into northern Italy associated with unusually warm dry summer in 2007

• **With expansion of Ae. albopictus and Ae. aegypti could expect more epidemics**
December 2013 – Local transmission reported for first time in the Americas

- Dominican Republic – 89,720
- Guadeloupe – 40,400
- Martinique – 35,000
- Haiti – 11,802
- Saint Martin (French) – 3,430
- Dominica – 2,363
- Saint Barthelemy - 620
- French Guyana - 390
- Sint Maarten (Dutch) – 123
- Puerto Rico - 23
- British Virgin Islands - 20
**Africa:** Activity follows periods of heavy rain which coincide with sea surface temperature anomalies in equatorial Pacific and Indian Oceans.

**East Africa:** Outbreaks are associated with exceptionally high rainfall amounts that flood grassland depressions “dambos” and support *Aedes* and *Culex* mosquitoes. Terminate with end of rainy season.
ROSS RIVER VIRUS

- **Australia**: Epidemics occur after unusually heavy rain.
- Climatological models show that a rise in sea level with greater rainfall and flooding could significantly increase virus activity.
• United States

• The weather in New York during the spring and summer of 1999, when the virus was presumably introduced, was particularly warm and humid, creating conditions that favored intensive mosquito breeding and efficient virus transmission.
• United States

• Since 1999 the largest outbreaks of human disease have been associated with **warm wet winters and springs** followed by **hot dry summers** which resemble some general circulation model projections for climate change over much of the US

• Currently experiencing earlier reemergence in spring and more rapid amplification in the summer that may be associated with early “heat waves”

<table>
<thead>
<tr>
<th></th>
<th>Total Cases</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>5,387</td>
<td>243 (4.5%)</td>
</tr>
<tr>
<td>Northeast</td>
<td>259</td>
<td>17 (6.5%)</td>
</tr>
</tbody>
</table>
West Nile Virus Isolations from Mosquitoes 1999 - 2013

Infected Mosquitoes
- 1-2 yr.
- 3-4 yrs.
- 5-6 yrs.
- 7-8 yrs.
- 9+ yrs.

Legend:
- Agric/Soil/Grass
- Forest
- Developed/Urbang
- Deep Water
- Wetland
High Risk Areas

West Nile Virus Human Cases 1999 - 2013

Human Cases
≥ 5 cases  = 1 case
= 2-4 cases  = acquired out of state

Agric/Soil/Grass
Forest
Developed/Urbn
Deep Water
Wetland
Northeastern US

- Experiencing a sustained resurgence of activity within long-standing foci (48 cases, 18 fatalities)

- Unprecedented northward expansion into new regions where the virus had been historically rare or previously unknown
Mosquito Species Range Expansions?

New State Records since 2005

Increased abundance and distribution

Mosquitoes Collected

1999-2005
2006-2011
2012

Oc. atlanticus
Oc. spencerii
Ps. howardii
Ps. columbiae
Cx. erraticus
Ae. albopictus
An. crucians
Predicted *Aedes albopictus* range expansion in the northeastern US under two climate change scenarios

Expansion and abundance associated with higher winter temperatures and precipitation (snowfall)

Distribution of *Aedes albopictus* in Connecticut
Distribution of *Anopheles crucians* in Connecticut
• The greatest effects of climate change on transmission of vector-borne diseases are likely to be observed at the temperature extremes of the range of temperatures at which transmission occurs
  – Increased pathogen transmission efficiency
  – Increased vector-host contact
  – Shortened extrinsic incubation period

• The effects are likely to be expressed in many ways
  – Short-term epidemics
  – Long-term gradual changes in disease trends
Concluding Thoughts

• “The natural history of mosquito-borne diseases are complex and the interplay of climate, ecology and vector biology defies simplistic analysis” (Reiter, Environ Health Per 2001)

• The recent resurgence of many of these diseases is a major cause for concern, but climate variability is only one factor

• Other principal determinants include local politics, economics and human activities
  – Demographic changes (population growth, migration, urbanization)
  – Societal changes (inadequate housing, water deterioration, migration)
  – Changes in public health policy (decreased resources for surveillance, prevention and vector control)
  – Insecticide and drug resistance
  – Deforestation
  – Irrigation systems and dams
Concluding Thoughts

- Adaptations to climate change and variability will largely depend on the level of health infrastructure in the affected regions.
- We really don’t know how projected climate change will affect the complex ecosystems required to maintain these mosquito-borne diseases.
- More research is needed to better understand the influence of weather and climate on these pathogens in their natural transmission cycles.
- Assessments that integrate global climate scenario-based analyses with local demographic and environmental factors will be needed to guide comprehensive, long-term preventive health measures.
Final Thought

I am afraid we are in for some very challenging times!