Climate Change and Infectious Diseases – The New Abnormal

Gerard (Jerry) Cangelosi, Ph.D.
Professor, Department of Environmental and Occupational Health Sciences
Adjunct Professor, Depts. of Global Health and Epidemiology
Phone: +1-206-543-2005
gcang@uw.edu

Disclosures: None
Climate Change and Infectious Diseases – The New Abnormal

1. What is an emerging or re-emerging infectious disease?
2. How do infectious diseases emerge/re-emerge?
3. How can climate change impact infectious disease emergence/re-emergence?
<table>
<thead>
<tr>
<th>Environmental changes</th>
<th>Human health impacts</th>
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<td>Social structures</td>
<td>Toxin exposure</td>
</tr>
<tr>
<td>Etc.</td>
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</tr>
</tbody>
</table>
Infectious disease
Adapted from Mayo Clinic: “disorders caused by (micro)organisms — such as bacteria, viruses, fungi, or parasites.”
Decline of infectious diseases

Global DALYs 1990 vs. 2013 (DALY = overall disease burden expressed as years lost due to ill-health, disability or early death)
Decline of infectious diseases

Crude U.S. mortality rates

http://jama.ama-assn.org/cgi/content/full/281/1/61/FIGJOC80862F2
Emerging Infectious Diseases

CDC: Infectious diseases whose incidence in humans has increased in the past 2 decades or threatens to increase in the near future. Examples:

- New infections resulting from changes or evolution of existing organisms
- Known infections spreading to new places or populations
- Previously unrecognized infections appearing in areas undergoing ecologic transformation
- Old or previously controlled infections reemerging as a result of antimicrobial resistance or breakdowns in public health.
Woolhouse and Gaunt, 2007

1399 recognized human pathogens
- 800 are zoonotic (capable of natural transmission between humans and animals)

87 new pathogens recognized since 1980
- Significance ranging from HIV to Mengale virus (2 cases known)
- Most are zoonotic

*Significance ranging from HIV to Mengale virus (2 cases known)
- Most are zoonotic

**Table 1**

<table>
<thead>
<tr>
<th>Taxonomic Category</th>
<th>No. spp.</th>
<th>No. spp. since 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>1399</td>
<td>87</td>
</tr>
<tr>
<td>Bacteria</td>
<td>541</td>
<td>11</td>
</tr>
<tr>
<td>Fungi</td>
<td>325</td>
<td>13</td>
</tr>
<tr>
<td>Helminths</td>
<td>285</td>
<td>1</td>
</tr>
<tr>
<td>Prions</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Protozoa</td>
<td>57</td>
<td>3</td>
</tr>
<tr>
<td>Viruses</td>
<td>189</td>
<td>58</td>
</tr>
<tr>
<td>DNA viruses</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td>RNA viruses</td>
<td>153</td>
<td>49</td>
</tr>
</tbody>
</table>

*R: Basic reproduction number
Average # of secondary cases per primary case in a new population
- Measles: 18
- Influenza virus: <1 to 3
## Comparison of recent epi/pandemics

<table>
<thead>
<tr>
<th>Year</th>
<th>Disease</th>
<th>Cases</th>
<th>Deaths</th>
<th>Case-fatality rate (CFR)</th>
<th>$R_0$ (various sources)</th>
<th>$R_0 &gt; 1$</th>
<th>$R_0 &lt; 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1918-1919</td>
<td>Spanish flu (estimated per CDC)</td>
<td>~500 million</td>
<td>50-100 million</td>
<td>10-20%</td>
<td>2-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002-2003</td>
<td>SARS-CoV (source: WHO)</td>
<td>8,422</td>
<td>916</td>
<td>9.6%</td>
<td>2-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006-2007</td>
<td>H5N1 “avian” flu (source: WHO)</td>
<td>508</td>
<td>302</td>
<td>59%</td>
<td>&lt;1 in humans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-2010</td>
<td>H1N1 “swine” flu (source: WHO)</td>
<td>622,482</td>
<td>14,286</td>
<td>0.03%</td>
<td>1.4-1.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Comparison of recent epi/pandemics

<table>
<thead>
<tr>
<th>Case</th>
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<th>Deaths</th>
<th>Case-fatality rate (CFR)</th>
<th>R₀ (various sources)</th>
</tr>
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<td>622,482</td>
<td>14,286</td>
<td>0.03%</td>
<td>1.4-1.6</td>
</tr>
<tr>
<td>Tuberculosis</td>
<td>8 million annually (2014)</td>
<td>1.5 million annually (2014)</td>
<td>38%</td>
<td>2-5</td>
</tr>
</tbody>
</table>

Tuberculosis wipes out San Francisco nearly twice per year

*A 5% annual increase in TB would kill more people in one year than all of these combined.
Figure 2 | Global richness map of the geographic origins of EID events from 1940 to 2004. The map is derived for EID events caused by all pathogen types. Circles represent one degree grid cells, and the area of the circle is proportional to the number of events in the cell.

Global trends in emerging infectious diseases

Kate E. Jones, Nikkita G. Patel, Marc A. Levy, Adam Storeygard, Deborah Balk, John L. Gittleman & Peter Daszak
<table>
<thead>
<tr>
<th>Disease event/re-emergence</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>European bat lyssavirus 1</td>
<td>1989</td>
</tr>
<tr>
<td>Hepatitis C virus</td>
<td>1989</td>
</tr>
<tr>
<td>Barmah Forest virus</td>
<td>1988</td>
</tr>
<tr>
<td>Picobirnavirus</td>
<td>1988</td>
</tr>
<tr>
<td>Dhori virus</td>
<td>1987</td>
</tr>
<tr>
<td>Sealpox virus</td>
<td>1987</td>
</tr>
<tr>
<td>Suid herpesvirus 1</td>
<td>1986</td>
</tr>
<tr>
<td>Borna disease virus</td>
<td>1985</td>
</tr>
<tr>
<td>Enterocytozoon bieneusi</td>
<td>1985</td>
</tr>
<tr>
<td>Pleistophora ronneafiei</td>
<td>1985</td>
</tr>
<tr>
<td>Human torovirus</td>
<td>1984</td>
</tr>
<tr>
<td>Rotavirus B</td>
<td>1984</td>
</tr>
<tr>
<td>Scedosporium proliferans</td>
<td>1984</td>
</tr>
<tr>
<td>Candiru virus</td>
<td>1983</td>
</tr>
<tr>
<td>Capnocytophaga canimorsus</td>
<td>1983</td>
</tr>
<tr>
<td>Helicobacter pylori</td>
<td>1983</td>
</tr>
<tr>
<td>Hepatitis E virus</td>
<td>1983</td>
</tr>
<tr>
<td>Human adenovirus F</td>
<td>1983</td>
</tr>
<tr>
<td>Human immuno-deficiency</td>
<td>1983</td>
</tr>
<tr>
<td>virus 1</td>
<td>1982</td>
</tr>
<tr>
<td>Borrelia burgdorferi</td>
<td>1982</td>
</tr>
<tr>
<td>Human T-lymphotropic Virus 2</td>
<td>1982</td>
</tr>
<tr>
<td>Seoul virus</td>
<td>1982</td>
</tr>
<tr>
<td>Microsporidian africanum</td>
<td>1981</td>
</tr>
<tr>
<td>Human T-lymphotropic Virus 1</td>
<td>1980</td>
</tr>
<tr>
<td>Puumala virus</td>
<td>1980</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartonella clarridgeiae</td>
<td>1997</td>
</tr>
<tr>
<td>Laguna Negra virus</td>
<td>1997</td>
</tr>
<tr>
<td>Andes virus</td>
<td>1996</td>
</tr>
<tr>
<td>Australian bat lyssavirus</td>
<td>1996</td>
</tr>
<tr>
<td>BSE/CJD agent</td>
<td>1996</td>
</tr>
<tr>
<td>Ehrlichia canis</td>
<td>1996</td>
</tr>
<tr>
<td>Juquitiba virus</td>
<td>1996</td>
</tr>
<tr>
<td>Metorchis conjunctus</td>
<td>1996</td>
</tr>
<tr>
<td>Usutu virus</td>
<td>1996</td>
</tr>
<tr>
<td>Bayou virus</td>
<td>1995</td>
</tr>
<tr>
<td>Black Creek Canal virus</td>
<td>1995</td>
</tr>
<tr>
<td>Cote d'Ivoire Ebola virus</td>
<td>1995</td>
</tr>
<tr>
<td>Hepatitis G virus</td>
<td>1995</td>
</tr>
<tr>
<td>New York virus</td>
<td>1995</td>
</tr>
<tr>
<td>Anaplasma phagocytophila</td>
<td>1994</td>
</tr>
<tr>
<td>Hendra virus</td>
<td>1994</td>
</tr>
<tr>
<td>Human herpesvirus 7</td>
<td>1994</td>
</tr>
<tr>
<td>Human herpesvirus 8</td>
<td>1994</td>
</tr>
<tr>
<td>Sabia virus</td>
<td>1994</td>
</tr>
<tr>
<td>Bartonella elizabethae</td>
<td>1993</td>
</tr>
<tr>
<td>Encephalitozoon intestinalis</td>
<td>1993</td>
</tr>
<tr>
<td>Gymnophalloides seoi</td>
<td>1993</td>
</tr>
<tr>
<td>Sin Nombre virus</td>
<td>1993</td>
</tr>
<tr>
<td>Bartonella henselae</td>
<td>1992</td>
</tr>
<tr>
<td>Dobrava-Belgrade virus</td>
<td>1992</td>
</tr>
<tr>
<td>Ehrlichia chaffeensis</td>
<td>1991</td>
</tr>
<tr>
<td>Encephalitozoon hellem</td>
<td>1991</td>
</tr>
<tr>
<td>Guanarito virus</td>
<td>1991</td>
</tr>
<tr>
<td>Nosema ocularum</td>
<td>1991</td>
</tr>
<tr>
<td>Banna virus</td>
<td>1990</td>
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<tr>
<td>Gan gan virus</td>
<td>1990</td>
</tr>
<tr>
<td>Reston Ebola virus</td>
<td>1990</td>
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<tr>
<td>Semliki Forest virus</td>
<td>1990</td>
</tr>
<tr>
<td>Trubanaman virus</td>
<td>1990</td>
</tr>
<tr>
<td>Vittaforma corneae</td>
<td>1990</td>
</tr>
<tr>
<td>Corynebacterium amycolatum</td>
<td>1989</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Disease emergence/re-emergences, 1980-2005</td>
<td></td>
</tr>
</tbody>
</table>

http://www.nap.edu/catalog/12586.html
Economic Impact of Selected Infectious Diseases

- SARS
  China, Hong Kong, Singapore, Canada
  $30-50 bn

- Foot & Mouth
  UK
  $25-30 bn

- BSE, UK
  $10-13 bn

- Foot & Mouth
  Taiwan, $5-8 bn

- Classical Swine Fever
  Netherlands, $2.3 bn

- BSE, Japan
  $1.5 bn

- Nipah, Malaysia
  $350-400 m

- HPAl, Italy
  $400 m

- Avian flu, NL
  $500 m

- BSE, Canada
  $1.5 bn

- BSE, US
  $3.5 bn

- Avian Flu, Asia
  $8-12 bn

Figures are estimates and are presented as relative size.

Source: BIO-ERA, LLC
• All infectious diseases require the convergence of pathogen, host, and environmental factors

• A new infectious disease can emerge when any of these three factors expands or shifts
• All infectious diseases require the convergence of pathogen, host, and environmental factors

• A new infectious disease can emerge when any of these three factors expands or shifts
Examples of new pathogens

1. New serotypes and variants
   - *E. coli* O157:H7 (acquisition of shiga-like toxin)
   - *Vibrio cholerae* O139
   - Pandemic influenza viruses e.g. H1N1/09
   - Chikungunya virus

2. Host range “jumps” due to genetic mutation
   - Zoonotic influenza e.g. bird flu
   - HIV-1 and HIV-2
   - SARS Coronavirus

3. Drug resistant strains
   - MDR-TB
   - MRSA
Infection “spectrum”

Persistence
Stable pathogen and host populations
Chronic infection and slow spread
“prudent”

Virulence
Unstable pathogen and host populations
Disease and rapid spread
“rapacious”

Some new pathogens have moved to the right on this scale due to genetic changes in the pathogen
• *E. coli* O157-H7
• Chikungunya virus

Others have recently moved into humans (or human subpopulations) as new hosts
• Limited evolutionary constraint on virulence
• Small outbreaks with significant mortality (CFR 10% to >50%)
• Examples:
  • Sin Nombre hantavirus
  • SARS coronavirus
  • Avian flu (H5N1)
New exposures
Examples of new exposures

1. Weather or climate changes
   - Affecting animal reservoirs
     - Sin Nombre Hantavirus outbreak, Four Corners area, 1993
   - Affecting insect vectors
     - Dengue
     - Malaria
   - Extreme weather
   - Water availability
   - Pathogen growth/survival in the environment
   - Desertification/dust

2. Spread through international travel and trade
   - West Nile Virus (insect vector spread)
   - SARS
   - Cholera
   - Zika

3. Migration, refugee movements, warfare
Examples of new exposures

4. Changes in human behavior (sexual, IV drug use, culinary, elective surgery)
   - Hepatitis C – IV drug use
   - Non-cholera vibrios (e.g. *V. vulnificus*) – uncooked seafood
   - Non-tuberculous mycobacteria – elective surgery, “lipotourism”
   - Sexually transmitted diseases

5. Habitat encroachment
   - Nipah virus (Fruit bats → Domestic pigs; Malaysia)
   - Borrelia (Lyme disease)

6. Dietary changes / bush meat
   - SARS coronavirus?

7. New disease management practices (e.g. MDR-TB in Peru)
Increasing host susceptibility

Exposures

Pathogens

Diseases

Susceptible hosts
Changes that have increased the number of susceptible hosts

1. Aging populations, prolonged life spans
   - e.g. non-tuberculous mycobacteria (NTM)
2. AIDS epidemic
3. Decline in vaccination rates
4. Medical procedures that compromise immunity
   - Healthcare-associated infections (HAI) in the U.S.: 1.7 million new cases and 99,000 deaths
     - *Pseudomonas aeruginosa*
     - *Clostridium difficile* ("C.dif")
     - *Acinetobacter baumannii*
     - MRSA
     - Etc.
Always consider diverse factors: Exposures, pathogens, hosts… and combinations of these things… and potential sources of bias.
How can **climate change** drive disease (re)emergence?

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<td>Chemical pollution</td>
<td>Cancer</td>
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<td>Nutrition</td>
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<td>Built environments</td>
<td>Infant mortality</td>
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</tbody>
</table>
Some climate impacts on infectious disease

- Exacerbating and expanding existing disease problems
  - Strain on and redirection of public health resources
  - Conflict and refugee movements
  - Nutritional and other stress
  - Migration
  - Urbanization, crowding
- Shifts in vector ranges
- Pathogen survival and growth in the environment
- Flooding and impacts on sanitation
- Air- and dust-borne diseases
- Harmful algae blooms
IPCC WGII AR5 Chapter 11:

- Until mid-century climate change will act mainly by exacerbating health problems that already exist.
- The largest risks will apply to populations that are currently most affected by diseases of poverty.
- Impacts on health will be reduced, but not eliminated, in populations that benefit from rapid social and economic development, particularly among the poorest and least healthy groups.
- The most effective adaptation measures for health in the near-term are programs that implement basic public health measures such as:
  - provision of clean water and sanitation
  - secure essential health care including vaccination and child health services
  - increase capacity for disaster preparedness and response
  - alleviate poverty.

Exacerbation and expansion of existing infectious disease problems
Tuberculosis, a globally prevalent disease of poverty

1. Caused by a bacterium, *Mycobacterium tuberculosis*
2. Airborne transmission, person-to-person
3. Limited vaccine (BCG)
4. Treatable, but long and difficult
5. Uneven distribution, but every country affected
Factors that impact TB incidence (Dye and Williams, 2010)

D: HIV (projected, Tanzania) (the single most important risk factor)

F: Health systems (Cuba)
Environmental changes that can increase TB incidence

- Breakdowns in public health systems
- Crowding, urbanization
- Population movement (including climate refugees)
- Antibiotic use
- Nutrition and other impacts on host susceptibility
- Exposure to animal reservoirs
- Changes in human behavior

Sputum samples await processing at Shyamoli TB Clinic, Dhaka, Bangladesh
# Climate change and vector-borne diseases

## Mosquito-borne diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Area</th>
<th>Cases-yr</th>
<th>Climate Sensitivity and Confidence in Climate Effect</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dengue</td>
<td>100 countries esp Asia Pacific</td>
<td>about 50 million</td>
<td><img src="image" alt="Climate icons" /></td>
<td>Beebe 2009, Descloux 2012, Earnest et al 2012, Pham et al 2011, Astrom et al 2012</td>
</tr>
</tbody>
</table>

## Tick-borne diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Area</th>
<th>Cases-yr</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tick-borne encephalitis</td>
<td>Europe, Russian Fed Mongolia, China</td>
<td>about 10,000</td>
<td>Tokarevich et al 2011</td>
</tr>
<tr>
<td>Lyme</td>
<td>Temperate areas of Europe, Asia, North America</td>
<td>about 20,000 in USA</td>
<td>Bennet 2006, Ogden et al 2008</td>
</tr>
</tbody>
</table>

## Other vector-borne diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Area</th>
<th>Cases-yr</th>
<th>Climate Sensitivity and Confidence in Climate Effect</th>
<th>Key references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemorrhagic fever with renal syndrome (HFRS)</td>
<td>Global</td>
<td>0.15 – 0.2 million</td>
<td><img src="image" alt="Climate icons" /></td>
<td>Fang et al 2010</td>
</tr>
<tr>
<td>Plague</td>
<td>Endemic in many locations worldwide</td>
<td>about 40,000</td>
<td><img src="image" alt="Climate icons" /></td>
<td>Stenseth et al 2006, Xu et al 2011, Ari et al 2010</td>
</tr>
</tbody>
</table>

## Climate drivers

- Temperature
- Precipitation
- Humidity

## Climate driver variables

- Increase or decrease: ![Climate icons](image)
- # of cases: More or Fewer
- Footnote: Effects are specific to Anopheles spp

## Confidence levels

- High confidence in global effect
- High confidence in local effect
- Low confidence in effect

---

IPCC WGII AR5 Table 11.1
## Vector-borne diseases with climate impacts
(modified from Wikipedia)

<table>
<thead>
<tr>
<th>Disease</th>
<th>Vector</th>
<th>Causative organism</th>
<th>Host</th>
<th>Symptoms</th>
<th>Area</th>
<th>Control/treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>African horse sickness</td>
<td>Culicoid midge</td>
<td>Orbivirus (virus)</td>
<td>Equids</td>
<td>Fever, lung, heart or mucous membrane symptoms.</td>
<td>Europe, Africa</td>
<td>Vaccination</td>
</tr>
<tr>
<td>Babesiosis</td>
<td>Tick</td>
<td>Babesia (protozoan)</td>
<td>Human, cattle</td>
<td>Fever then red urine</td>
<td>South Europe and Africa</td>
<td>Antibiotics</td>
</tr>
<tr>
<td>Chagas disease (American trypanosomiasis)</td>
<td>Various assassin bugs of subfamily Triatominae</td>
<td>Trypanosoma cruzi (protozoan)</td>
<td>Human, cattle</td>
<td>Mild symptoms, then chronic heart or brain inflammation</td>
<td>Central and South America</td>
<td>Antiparasitic drugs; treatment of symptoms</td>
</tr>
<tr>
<td>Dengue fever</td>
<td>Mosquito</td>
<td>Flavivirus (virus)</td>
<td>Human</td>
<td>Fever then arthritis</td>
<td>(Sub) tropics and South Europe</td>
<td>Observation/supportive treatment</td>
</tr>
<tr>
<td>Tick-borne encephalitis</td>
<td>Tick</td>
<td>Tick-borne encephalitis virus</td>
<td>Ill with flu then meningitis</td>
<td>Central and North Europe</td>
<td>Prevention and vaccination</td>
<td></td>
</tr>
<tr>
<td>Leishmaniasis</td>
<td>Sandfly</td>
<td>Leishmania (protozoan)</td>
<td>Human</td>
<td>Fever, damage to the spleen and liver, and anaemia</td>
<td>South hemisphere and Mediterranean Countries</td>
<td>Treatment of infected</td>
</tr>
<tr>
<td>Lyme disease</td>
<td>Tick</td>
<td>Borrelia burgdorferi (bacterium)</td>
<td>Deer, human</td>
<td>Skin rash then paralysis</td>
<td>Europe, North Africa, and North America</td>
<td>Prevention and antibiotics</td>
</tr>
<tr>
<td>Malaria</td>
<td>Mosquito</td>
<td>Plasmodium (protozoan)</td>
<td>Human</td>
<td>Headache then heavy fever</td>
<td>(Sub) tropics</td>
<td>Prevention and anti-malaria</td>
</tr>
<tr>
<td>Plague</td>
<td>Flea</td>
<td></td>
<td>Human</td>
<td></td>
<td></td>
<td>Prevention and Antibiotics</td>
</tr>
<tr>
<td>Rickettsial diseases: Typhus, rickettsialpox, Boutonneuse fever, African tick bite fever, Rocky Mountain spotted fever etc.</td>
<td>Tick, lice</td>
<td>Rickettsia species (bacteria)</td>
<td></td>
<td>Global</td>
<td>Prevention and antibiotics</td>
<td></td>
</tr>
<tr>
<td>African trypanosomiasis (sleeping sickness)</td>
<td>Tsetse fly</td>
<td>Trypanosoma brucei (protozoan)</td>
<td>Wild mammals, cattle, human</td>
<td>Fever, joint pain, swollen lymph nodes, sleep disturbances</td>
<td>Sub-Saharan Africa</td>
<td>Various drugs</td>
</tr>
<tr>
<td>West Nile disease</td>
<td>Mosquito</td>
<td>West Nile virus</td>
<td>Birds, human</td>
<td>Fever then meningitis</td>
<td>Africa, Asia, North America, South and East Europe</td>
<td>None</td>
</tr>
</tbody>
</table>
Don’t forget nematode-borne diseases (WHO)

Chikungunya
Viral disease transmitted to humans by infected mosquitoes
Congo-Crimean haemorrhagic fever
Severe illness caused by a number of viruses
Dracunculiasis
Infection caused by drinking-water containing water fleas that have ingested Dracunculus larvae
Lymphatic filariasis
Infection occurs when filarial parasites are transmitted to humans through mosquitoes
Onchocerciasis
Parasitic disease caused by the filarial worm onchocerca volvulus
Schistosomiasis
Parasitic disease caused by trematode flatworms of the genus
Malaria

- Globally prevalent life-threatening infection
  - > 1 million deaths/yr
  - 300-500 million infections/yr
- ~90% of deaths occur in sub-Saharan Africa
- most victims are children <5 yrs
- Pregnant women are also especially vulnerable.
Temperature and Mosquitos

- Faster life cycle in warmer temperatures
- Extended mosquito season due to elevated temperatures
- Insects bite more actively in warmer temperatures
- Expansion of suitable habitat
- However, there are upper temperature limits which might be exceeded in many places
Model: Cooler temperatures (higher elevations)
- Slow parasite development and reproduction within mosquito salivary gland
- Reduce biting rate of mosquito

Do warmer temperatures increase malaria at higher elevations over multiple years?

Potential confounding factors: Malaria incidence from year to year affected by
- Treatment programs
- Resistance patterns
- Land use changes
- Migration
- Access to health care
- Etc. etc.

Challenge: Compare spatial (altitude) distribution of cases across time in a way that is independent of temporal variation (short- and long-term) variations in disease burden.

Solution: Compare temperature to median altitude of case occurrence (altitude at which 50% of cases occurred above and 50% occurred below). This value was independent of total case count.
Fig. 2. Changes in altitudinal distribution of malaria cases with mean temperature across years. Altitudinal cumulative distributions of cases for Ethiopia (top row) and Colombia, western region (bottom row) are shown as a function of time, as well as mean temperatures preceding the transmission season. (A and D) The altitudinal cumulative curves generated with the incidence data in two given years, together with the location of the 50th percentile and its corresponding altitude. By definition, this is the altitude at which 50% of the cases occur below and 50%, above in the altitudinal gradient. A shift of this cumulative curve to the right indicates that more malaria cases have occurred at higher altitudes in a given year. This does not mean the number of cases has increased from 1994 to 1997 but that the distribution of the disease has moved toward a higher elevation. (B and E) The corresponding scatter plots of the median altitude against mean temperatures, demonstrating a movement of the distribution to higher altitudes in warmer years for the two highland regions. (C and F) Show the yearly variation in the median altitude of cases (blue line), together with the mean temperatures in the critical 4-month window for the two regions (red line) (fig. S5). Uncertainty in the median value is estimated by bootstrap resampling (23) and is shown as ±1 SD in the plots. (The eastern region of Colombia exhibits similar patterns to those shown here for the western region.)
Malaria projections (IPCC)

- Keeping climate constant, and assuming strong economic growth and social development (best case), 1.74 billion people projected to be at risk by 2050. This is ~50% of the current number.
  - Total world population ~8.5 billion.

- Factoring in climate change increases this number to 1.95 billion.

- With climate change and without economic development, the number increases to 5.2 billion.

- Return of malaria to North America and Europe are difficult to predict, however vectors exist and the disease has returned in some places facing economic hardship, e.g. Greece.
Yellow fever outbreak in Philadelphia, summer 1793

- Severe “El Nino” → hot summer
- mosquitos proliferated
- At the same time, 2000 refugees arrived from Saint Domingue (now Haiti), following slave rebellion and Yellow fever outbreak on the island.
- 5000 deaths in Philadelphia in 3 months, 20,000 fled the city.
- Sketchy responses: “Bleeding”, use of black nurses thought to be immune, quarantine of incoming ships, religious initiatives
- Ended with autumn frosts
- Aftermath
  - Late 1880’s: Mosquito vector identified by Dr. Carlos Finlay (Cuba) and experiments with volunteers conducted by Dr. Walter Reed (US Medical Army Corps).
  - Vaccine developed in 1937.

Zika virus emergence in the Americas 2015-2016

- Transmitted by *A. aegypti*, possibly other species
- Mild disease in adults but can cause microcephaly and brain damage during prenatal infection
- Endemic to Africa. Spread to Asia ~50 years, now arriving the Americas.

*Aedes aegypti*

**Dengue**
Zika virus emergence in the Americas 2015-2016

• Transmitted by *A. aegypti*, possibly other species
• Mild disease in adults but can cause microcephaly and brain damage during prenatal infection
• Endemic to Africa. Spread to Asia ~50 years, now arriving the Americas.
• More problematic in immunologically naïve populations.

How Zika spread (based on phylogenetic and epidemiological analysis)
Source: Wikimedia Commons
Food/waterborne disease

- a leading cause of child mortality and morbidity worldwide
What are food- and waterborne infections?

Adapted from IPCC WGII AR5:

Food- and waterborne infections are caused by
• ingestion of contaminated water or food
• Incidental ingestion during swimming
• by direct contact with eyes, ears or open wounds.

Pathogens in water may be
• Suspended in water ("planktonic")
• Associated with surfaces (biofilms)
• Zoonotic
• concentrated by shellfish (e.g., oysters)
• deposited on irrigated food crops.

Pathogens of concern include
• enteric organisms (bacteria, protozoa, or viruses) that are transmitted by the fecal-oral route
• bacteria and protozoa that occur naturally in aquatic systems.
• pathogens or colonizers of zoonotic reservoirs
Adapted from IPCC WGII AR5:

Climate may act by

- Directly influencing growth, survival, persistence, transmission, or virulence of pathogens

- Indirectly through climate-related perturbations in local ecosystems or the habitat of species that act as zoonotic reservoirs.

- Indirectly through perturbation of control measures including drinking water safety, surveillance, or treatment

Rotavirus

Campylobacter jejuni

Entamoeba histolytica
Risk to the safe and effective operation of our sewerage systems.

- Toilets are gravity-powered. Sewerage is built on or under ground at lower levels than your house.
- A significant fraction of us live near sea level
- Rising sea levels can impede wastewater flowing out.
- Saline sea-water can corrode pipes, pumps etc. not designed to deal with it.
- Extreme weather events can damage systems.
  - In the US, Cyclone Sandy created enormous sewage pollution from storm surges and coastal flooding. The system was swamped and damage was caused to sewers, pumps and treatment plants. The cost of repairs is estimated at US$2 billion.
- Mitigation will be expensive. Under the best scenarios, “expiring” facilities will need to be relocated.
**Vibrios**

Examples of pathogens that proliferate in aquatic (including marine) environments, AND are transmitted by the fecal-oral route.

- *Vibrio cholerae*, causative agent of cholera (WHO)
- Extremely virulent diarrheal disease that can kill within hours if untreated.
- 3–5 million cases and 100,000–120,000 deaths every year.
- Endemic in many developing countries.
- The main reservoirs are people and aquatic sources such as brackish water and estuaries, often associated with algal blooms, copepods, and other plankton.
- Control of plankton ingestion, e.g. course filtration, can reduce cholera.
- Typical at-risk areas include peri-urban slums and refugee camps.
**Vibrios**

Climate role in cholera (sources: WHO, IPCC, and Yale Environment 360 [http://e360.yale.edu/feature/climates_strong_fingerprint__in_global_cholera_outbreaks/2371/])

- Populations of *Vibrio cholerae* in coastal waters, estuaries, and bays rise and fall in association with environmental factors.
  - Significant climate-related driver: Proliferation of copepods and other hosts.
  - In Peru, *V. cholerae* levels have been linked to the temperature of local rivers.
  - In Italy, to the surface temperatures of estuaries along the Adriatic coast.
  - In Mexico, *V. cholerae* in lagoon oysters increase as seas warm.
  - In the Chesapeake Bay, *V. cholerae* levels increase during the summer.
  - In Bangladesh, cholera risk increases by 2-4X in the 6 weeks following a 5°C spike in water temperature.
  - In Ghana, an analysis of 20 years of data revealed a correlation between cholera incidence and rainfall and land surface temperatures.
  - In Djibouti, Somalia, Kenya, Mozambique, and Tanzania, cholera epidemics have been correlated with flooding as well as sea surface temperatures.
  - Analysis of 70 years of data on cholera prevalence in Bangladesh revealed an association between cholera incidence and increasingly intense El Nino events that began in 1980.
  - Statistical modeling has found correlations between the pattern of infections in Peru with El Nino events. This may have played a role in a massive cholera outbreak in Peru that occurred during El Nino in 1991.
  - Correlations are strong enough to facilitate tracking and prediction.
  - Additional drivers: Indirect through impacts on sanitation, infrastructure, surveillance, patient care.
Discount sushi for thought: Non-cholera vibrios

- Mainly *V. parahaemolyticus* and *V. vulnificus*
- Estimated 8,000 infections and 57 deaths in the U.S. each year.
- Natural inhabitants of marine coastal and estuarine environments. Populations increase dramatically during the warm summer months.
- Consuming raw, undercooked, or cross-contaminated seafood, especially shellfish, is the most common cause of infection.
- *V. parahaemolyticus* infection causes acute gastroenteritis with fever.
- *V. vulnificus* causes septicemia in persons with immunocompromising conditions, chronic liver disease, and alcoholism. Fifty percent of patients with septicemia die.
“This report documents a large outbreak of *V. parahaemolyticus* serotype O6:K18 in the United States, and it expands the range of epidemiologically confirmed *V. parahaemolyticus* illness to a latitude higher than 60 degrees — more than 1000 km north of British Columbia, previously the northernmost area reported to have locally acquired illness.”
• Prior to 2004, Alaskan waters were thought to be too cold to support *V. parahaemolyticus* at levels high enough to cause disease.

• July 2004: Notice of outbreak on cruise ship in Prince William Sound

• Active surveillance identified 62 cases (acute onset of watery diarrhea that started ≤2 days after consuming raw oysters).

• All oysters associated with the outbreak were harvested locally when mean daily water temps exceeded 15°C.

• Since 1997 water temps have been steadily increasing in the area, and 2004 was the first year when mean daily temps did not drop below 15°C. 

*Bakedalaskaproject.com*
“Conclusions
This investigation extends by 1000 km the northernmost documented source of oysters that caused illness due to *V. parahaemolyticus*. Rising temperatures of ocean water seem to have contributed to one of the largest known outbreaks of *V. parahaemolyticus* in the United States.”

“Many of the serotypes reported in this study have also been found in Puget Sound.....These findings suggest an exchange of *V. parahaemolyticus* between Puget Sound and Alaska, possibly through migrating sea birds or marine mammals or the discharge of ballast water.”
Health impacts of airborne particles

• Lung disease → susceptibility to respiratory infections
• Aeroallergens (IPCC WGII AR5)
  • Increase CO2 → more plant allergens
  • Droughts and winds in some places → more exposure (similar to dust)
  • Increased heat and humidity in some places → more mold
• Some particles are soil-borne pathogen spores; others are dust particles that carry pathogens
Wind- and dust-associated infectious diseases

Table 1: Soil borne infections diseases (bold) and their causative agents (italics) split into two groups, “Euedaphic pathogenic organisms (EPOs)” and “Soil Transmitted Pathogens (STPs)”, depending on the closeness of their relationship with soil.

<table>
<thead>
<tr>
<th>Euedaphic pathogenic organisms</th>
<th>Soil Transmitted Pathogens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinomycetoma: <em>e.g.</em> Actinomyces israelii</td>
<td>Poliovirus</td>
</tr>
<tr>
<td>Anthrax: <em>Bacillus anthracis</em></td>
<td>Hantavirus</td>
</tr>
<tr>
<td>Botulism: <em>Clostridium botulinum</em></td>
<td>Q Fever: <em>Coxiella burnetii</em></td>
</tr>
<tr>
<td>Campylobacteriosis: <em>e.g.</em> Campylobacter jejuni</td>
<td>Lyme disease: <em>Borrelia</em> sp.</td>
</tr>
<tr>
<td>Leptospirosis: <em>e.g.</em> <em>Leptospira interrogans</em></td>
<td>Ascariasis: <em>Ascaris lumbricoides</em></td>
</tr>
<tr>
<td>Listeriosis: <em>Listeria monocytogenes</em></td>
<td>Hookworm: <em>e.g.</em> <em>Ancylostoma duodenale</em></td>
</tr>
<tr>
<td>Tetanus: <em>Clostridium tetani</em></td>
<td>Enterobiasis (Pinworm)</td>
</tr>
<tr>
<td>Tularemia: <em>Francisella tularensis</em></td>
<td>Strongyloides: <em>e.g.</em> <em>Strongyloides stercoralis</em></td>
</tr>
<tr>
<td>Gas Gangrene: <em>Clostridium perfringens</em></td>
<td>Trichuriasis (Whipworm): <em>Trichuris trichiura</em></td>
</tr>
<tr>
<td>Yersiniosis: <em>Yersinia enterocolitica</em></td>
<td>Echinococcosis: <em>e.g.</em> <em>Echinococcus multilocularis</em></td>
</tr>
<tr>
<td>Aspergillosis: <em>Aspergillus</em> sp.</td>
<td>Trichinellosis: <em>Trichinella spiralis</em></td>
</tr>
<tr>
<td>Blastomycosis: <em>e.g.</em> <em>Blastomyces dermatitidis</em></td>
<td>Amoebiasis: <em>Entamoeba histolytica</em></td>
</tr>
<tr>
<td>Coccidioidomycosis: <em>e.g.</em> <em>Coccidiodes immitis</em></td>
<td>Balantidiasis <em>Balantidium coli</em></td>
</tr>
<tr>
<td>Histoplasmosis: <em>Histoplasma capsulatum</em></td>
<td>Cryptosporidiosis: <em>e.g.</em> <em>Cryptosporidium parvum</em></td>
</tr>
<tr>
<td>Sporotrichosis: <em>Sporothrix schenckii</em></td>
<td>Cyclosporiasis: <em>Cyclospora cayetanensis</em></td>
</tr>
<tr>
<td>Mucormycosis: <em>e.g.</em> <em>Rhizopus</em> sp.</td>
<td>Giardiasis: <em>Giardia lambia</em></td>
</tr>
<tr>
<td>Mycetoma: <em>e.g.</em> <em>Nocardia</em> sp.</td>
<td>Isosporiasis: <em>Isospora belli</em></td>
</tr>
<tr>
<td>Strongyloidinosis: <em>e.g.</em> <em>Strongyloides stercoralis</em></td>
<td>Toxoplasmosis: <em>Toxoplasma gondii</em></td>
</tr>
<tr>
<td>Shigellosis: <em>e.g.</em> <em>Shigella dysenteriae</em></td>
<td>Pseudomonas aeruginosa</td>
</tr>
<tr>
<td>Eschericia coli</td>
<td><em>Salmonella enterica</em></td>
</tr>
</tbody>
</table>
Valley fever (Coccidioidomycosis)

- Fungal disease caused by *Coccidioides immitis* or *Coccidioides posadasii*
- Lives as mycelium in soil of SW USA, central and South America.
- “Grow and blow”: Dormant during dry spells, rain causes it to grow and form spores. If this is followed by a disruption (windstorm, plowing, construction, earthquakes), outbreaks can ensue.
- Overall, ~20,000 cases/year in U.S. (CDC)
  
  Compare:
  - WNV: ~2,500 cases/year
  - TB: ~10,000 cases/year

- Up to ~150,000 may be infected each year (CDC)
Environmental/climate change drivers of dust exposure

- More drought
- Expanding deserts
- Expansion of farming → More farm dust
- Construction → dust
- More wind and dust storms in some places.
- Exposure of immunologically naïve people due to urban expansion (e.g. sprawl in CA) and migration.
Harmful algal blooms (HAB) and cyanobacterial harmful algal blooms (cyanoHABs)

Climate changes that may increase marine HABs

- Increased marine CO₂ concentration and acidification
  - Algal growth
  - Toxin production
- Increased nutrients in some areas due to
  - Desertification (iron blown into sea)
  - Run-off
- Rising temperature
- Some changes may cut both ways, resulting in relocation rather than net increases
  - Increased storms
  - Rising sea levels

- Tatters AO, High CO2 promotes the production of paralytic shellfish poisoning toxins by Alexandrium catenella from Southern California waters. Harmful Algae 30 (2013) 37–43
Environment changing? Hello, infectious disease

Valley fever (Coccidioidomycosis)

- Usually acquired by inhalation
- Most infected people do not develop disease
- Usually but not always associated with immunodeficiency. Dosage and strain may be important.
- Disease symptoms caused by inflammation due to endospores; typically flu-like: fever, cough, exhaustion. Usually self-resolving
- Rarer cases require antifungal treatment (e.g. azoles):
  - Chronic pulmonary infections
  - Extrapulmonary infections (especially CNS)