


# Climate and Human Health Responders Course for Health Professionals

## Vector-borne Disease

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NOAA
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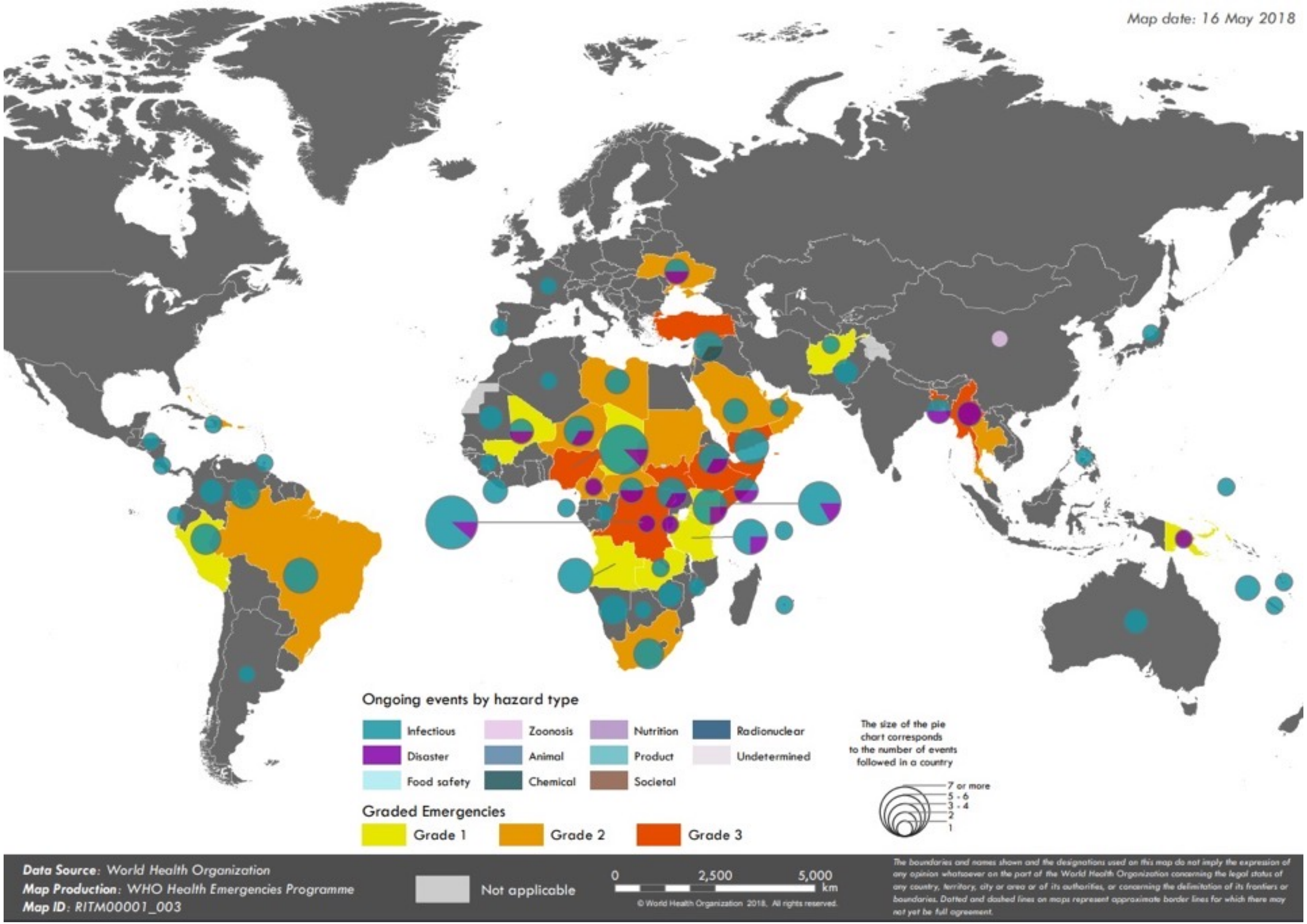
# Vector-borne Disease

## *Learning Objectives*

- Explain the environmental processes changing as result of climate change and how they impact the prevalence, incidence, and distribution of vector-borne disease
- For the following diseases, describe how climate change is influencing their distribution: Lyme disease, Dengue fever, Malaria, Hantavirus, West-Nile virus
- Explore what actions health professionals can take to protect patients vulnerable to these diseases
- Identify vulnerable populations including: women, outdoor workers, children, immunocompromised, etc
- Define steps the health sector can take to become prepared to address shifting geographic burdens of vector-borne disease, including increasing surveillance and early-warning systems

# Disclosure Information

No disclosures



Map date: 16 May 2018
Ongoing events by hazard type
Infectious
Disaster
Food safety
Zoonosis
Animal
Chemical
Nutrition
Product
Societal
Radionuclear
Undetermined
The size of the pie chart corresponds to the number of events followed in a country
7 or more
5 - 6
3 - 4
2
1
Graded Emergencies
Grade 1
Grade 2
Grade 3
Data Source: World Health Organization
Map Production: WHO Health Emergencies Programme
Map ID: RITM00001_003
Not applicable
0
2,500
5,000
km
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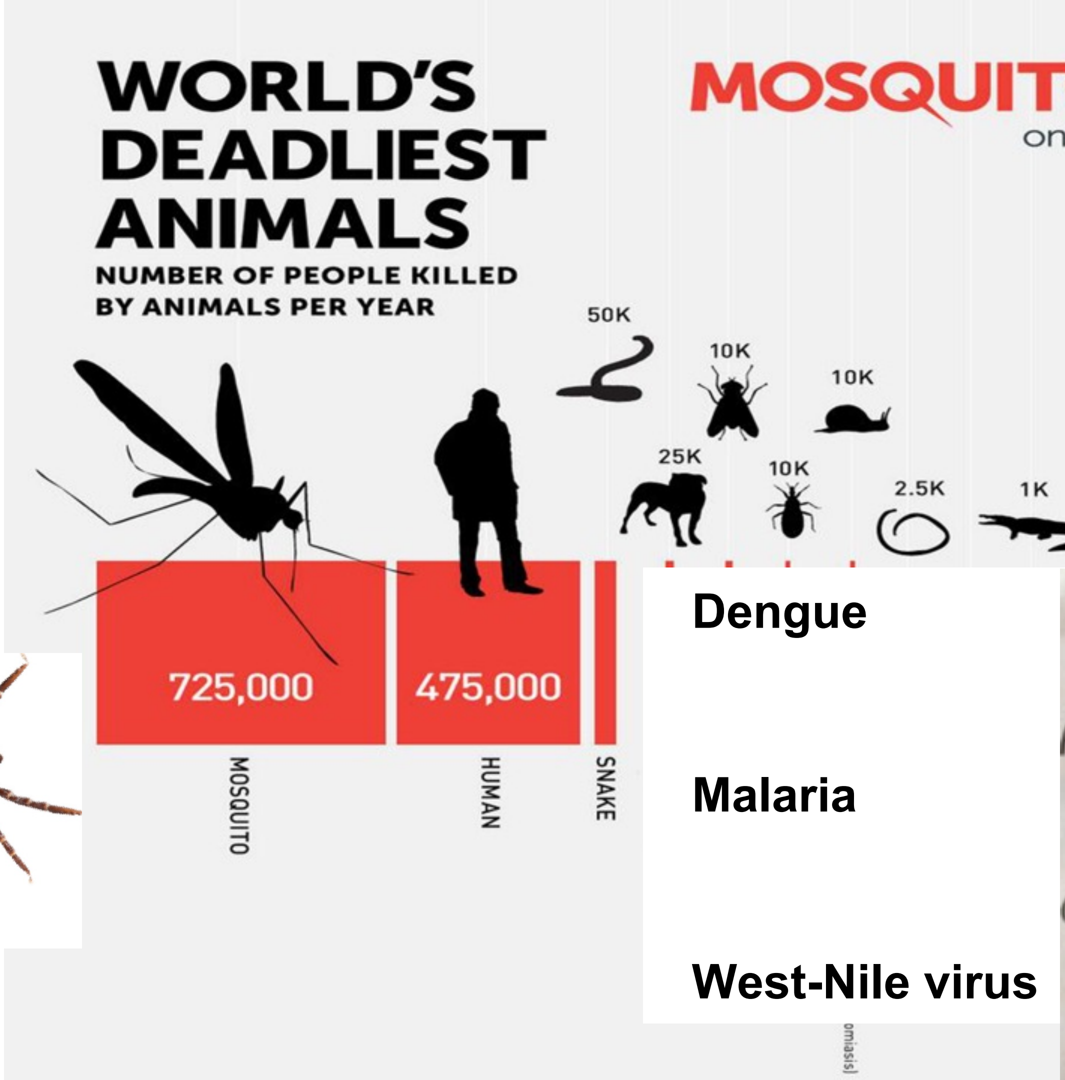
The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

# Interconnected web of life

- Climate change is shifting all of the natural systems
- The range, life cycle, growing pattern and disease dynamics of many living organisms are affected by changing climate conditions
- Human health is inextricably linked to the health of animals, plants and ecosystems
- “One health” and “planetary health” approaches are necessary to evaluate the effects
- Changes in climate influence habitat suitability and reproductive rate for host, vector, and infectious organism of some infectious diseases



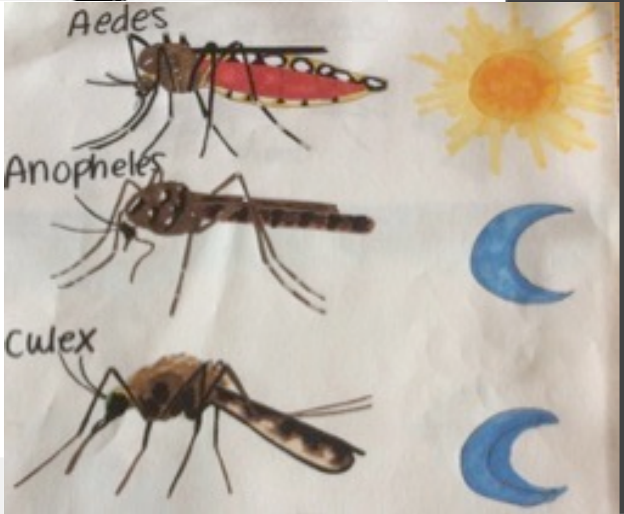

**Hanta**


**Lyme**

**Dengue**

**Malaria**

**West-Nile virus**



# You mean there's more than one kind of mosquito vampire??

***Culex***

Feeds at dusk and dawn

WNV

***Aedes***

Feeds during the day

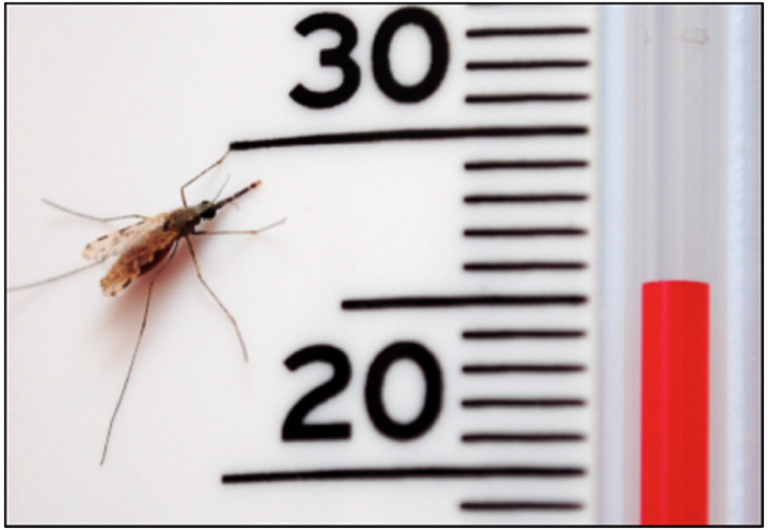
Dengue

***Anopheles***

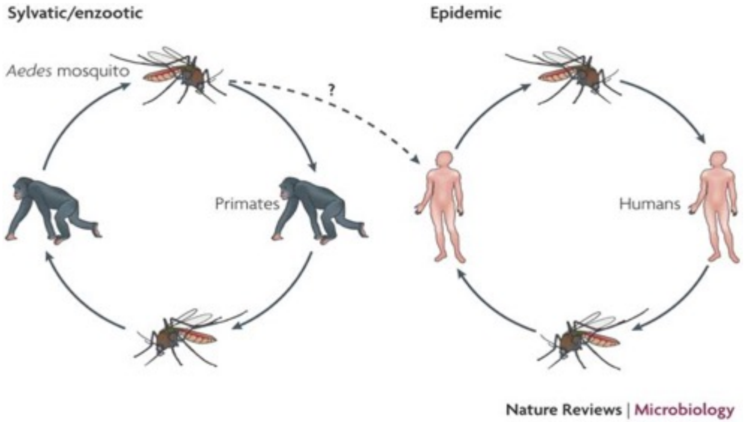
Feeds at night

Malaria

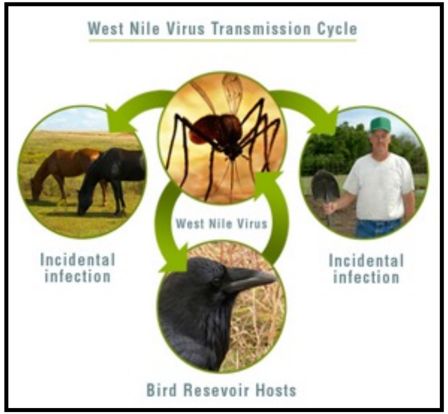
# How will climate change affect vector-borne disease transmission?

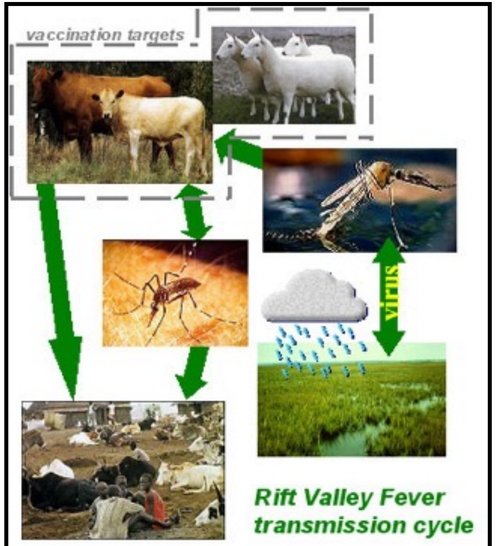


# Vector-Borne Diseases: What are Arboviruses?




- ***Diseases spread by arthropods***
- Require a blood sucking arthropod to complete the life cycle
- Often zoonotic – animal to human transmission
- ***Ar***thropod-***bo***rne viruses
  - At least 500 viruses
  - Diverse: 8 viral families
    - *Togaviridae, Flaviviridae, and Bunyaviridae*



# What is Climate Change?

# Major Emerging and Reemerging Infectious Disease Outbreaks, 2002-2015

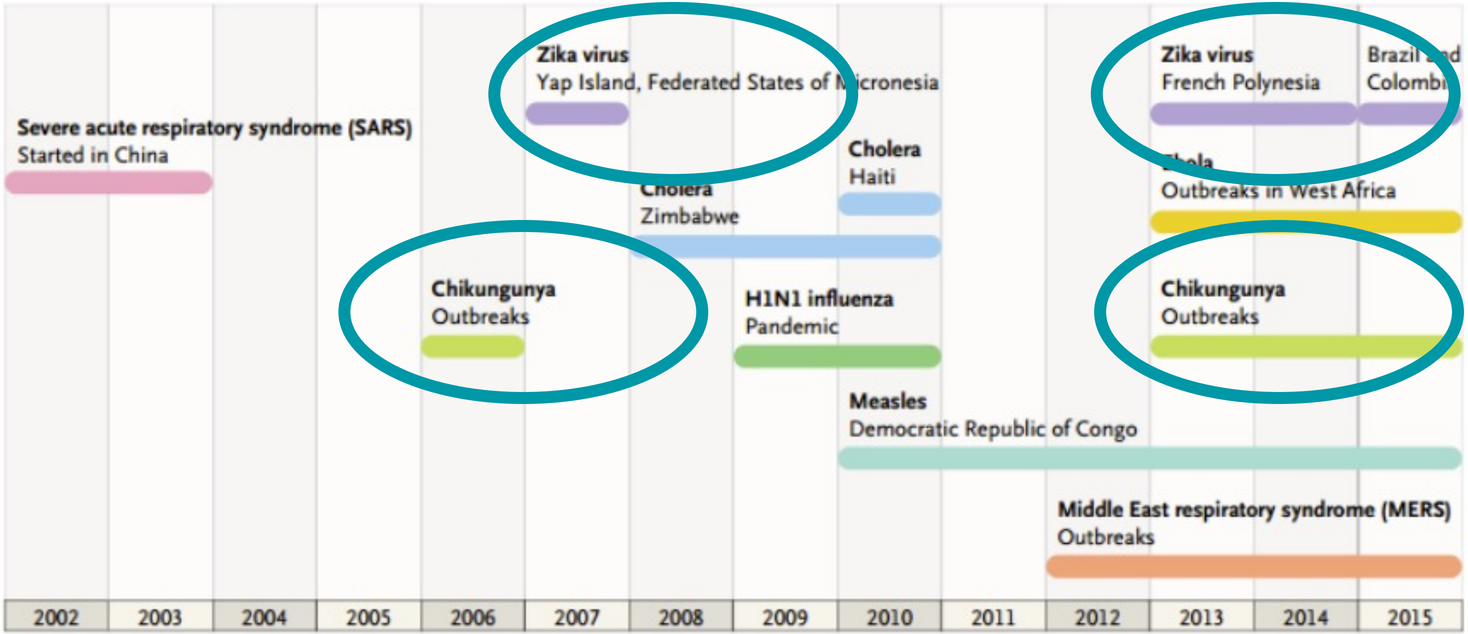



Figure 1. Major Emerging and Reemerging Infectious-Disease Outbreaks, Epidemics, and Pandemics, 2002 through 2015.

National Academy of Medicine, 2016

# Disease Emergence: Influences of Modern Life

- Urbanization
- Land Use Change: Deforestation/Reforestation, Land Reclamation, Irrigation Projects
- Military Activities/War
- Reduced/Ineffective Vector Control
- Increased Transportation

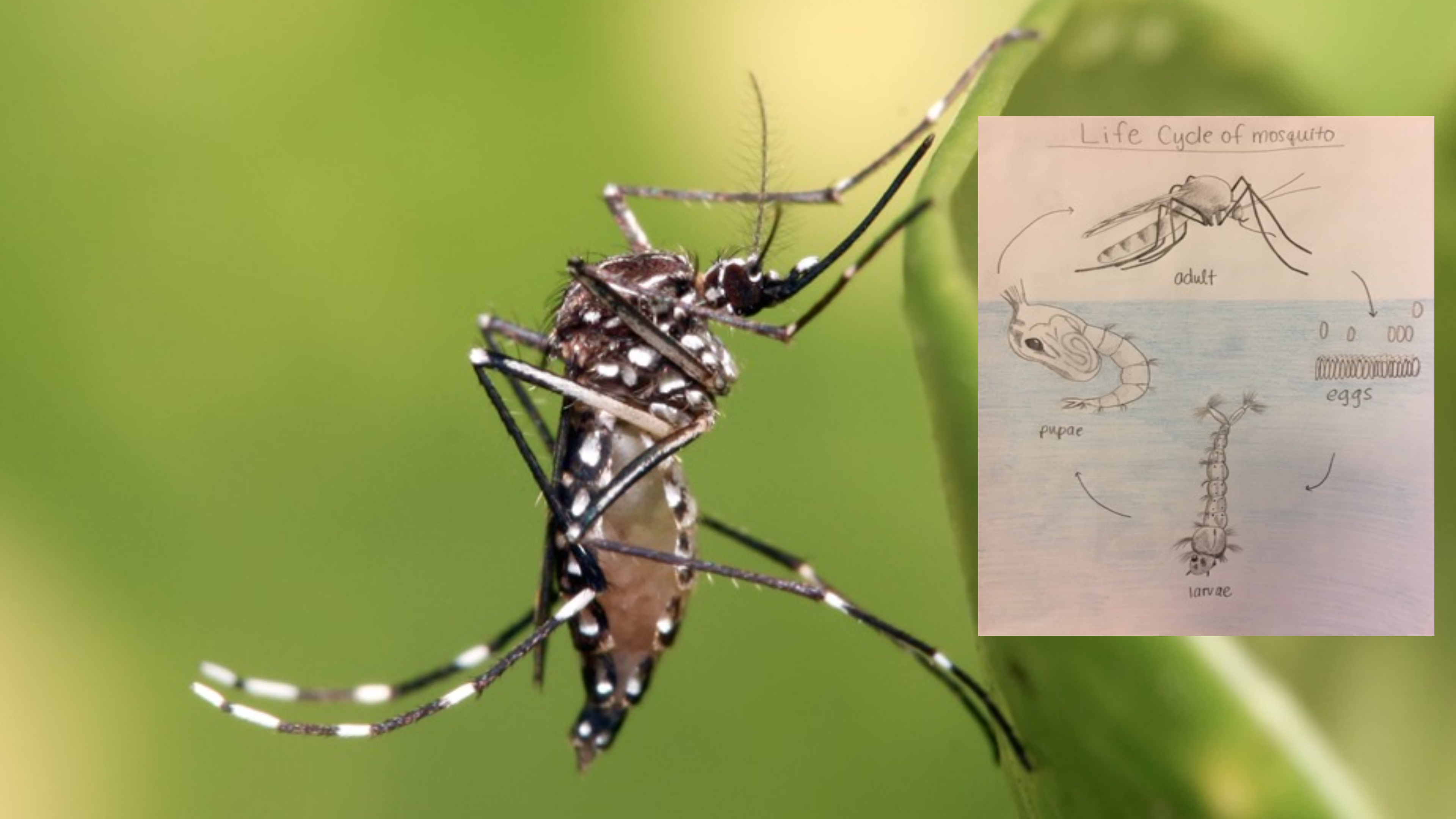
- Climate Change
  - Natural Disasters
  - Extreme Weather Events
  - Reduced Capacity to Sustain Clean Water

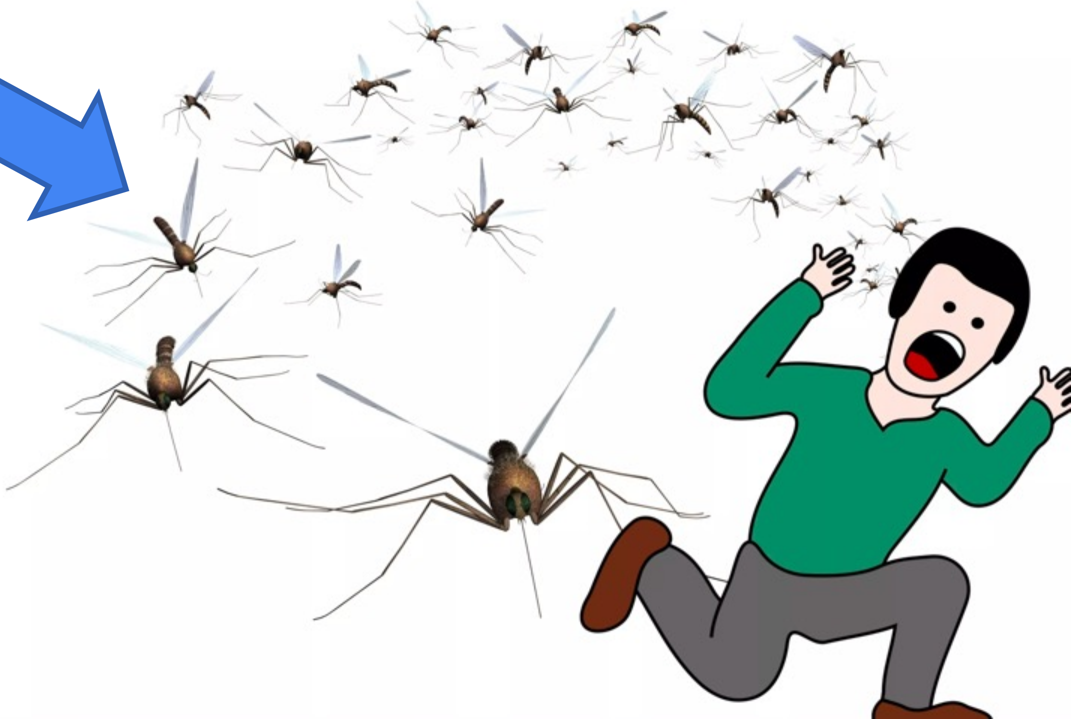
# Extreme Weather Events Are More Frequent

# Extreme climate impact on dengue virus transmission in Kenya

- Using satellite-derived climate data, we classified months that experienced highly abnormal rainfall and temperature as extreme climate events (floods, droughts, heat waves, or cold waves)
- Compared the average vector abundance and cases of dengue infection following extreme climate months using lag periods of one month and two months, respectively
- **Floods** resulted in significantly increased vector abundance and generally higher risk of dengue infection

Nosrat et al. PLoS NTDs 2021


Life Cycle of mosquito
adult
eggs
larvae
pupae

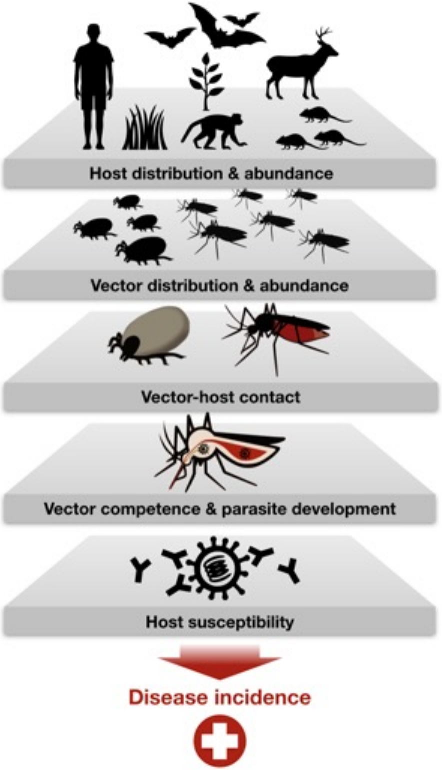


# Interactions between climate change and infectious diseases are complex and poorly understood

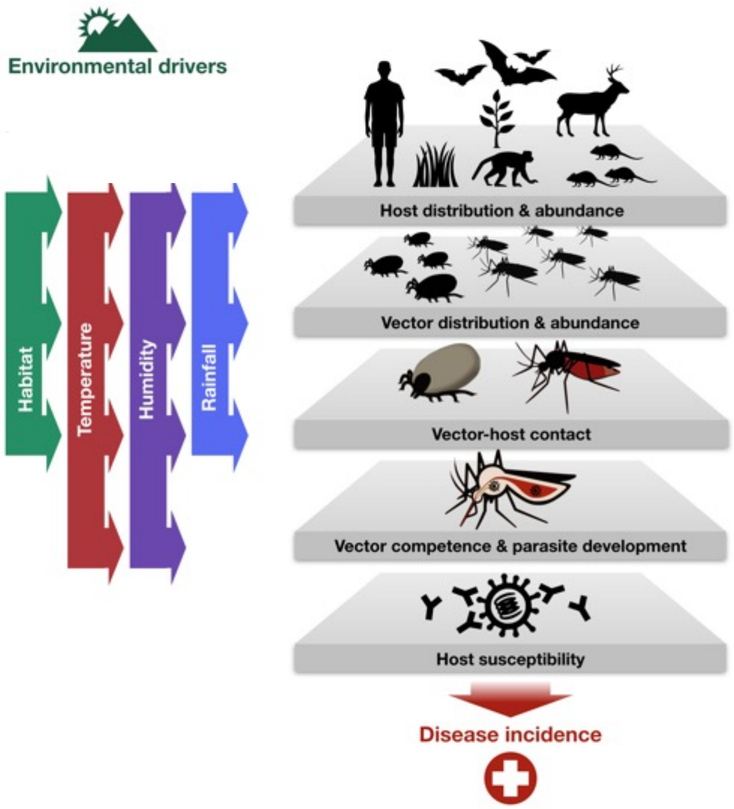
- Chikungunya is spread by a day biting mosquito (*Aedes aegypti*) which prefers to breed in man-made plastic containers
- 2004-5 Kenyan chikungunya outbreak linked to drought
    - Unusually dry, warm conditions preceded the outbreaks, including the driest since 1998 for some of the coastal regions
    - Infrequent replenishment of domestic water stores and elevated temperatures may have facilitated transmission
    - Underscores the need for safe water storage during drought relief operations




Chretien et al. AJTMH 2007




Shocket et al(2020) In Population Biology of Vector-borne Diseases (pp. 85-118). Oxford University Press.

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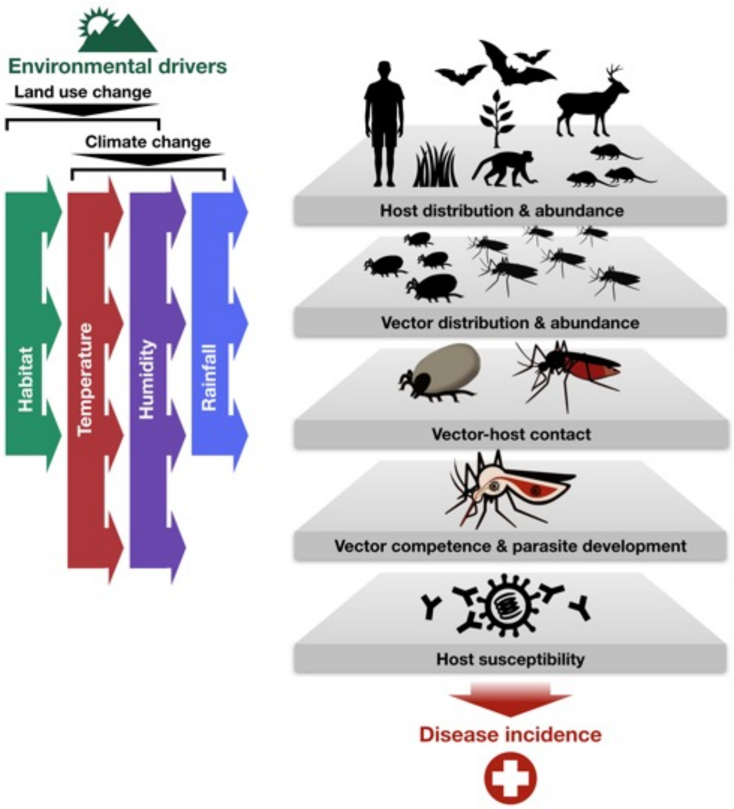
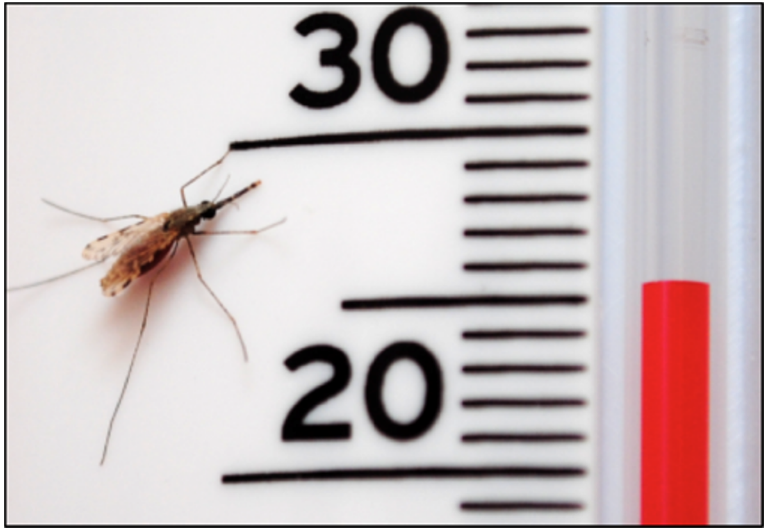
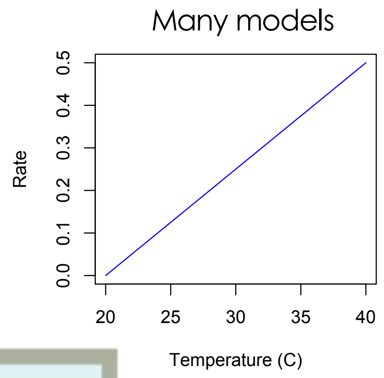


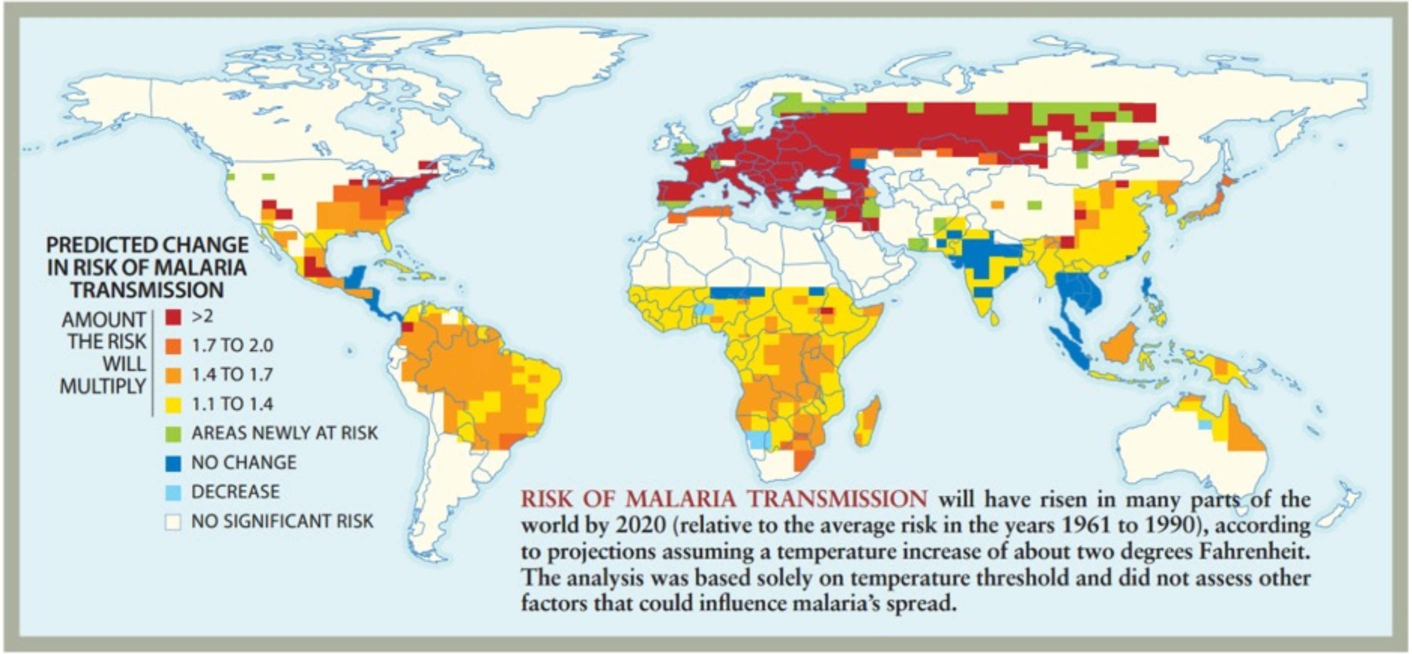

Shocket et al(2020) In Population Biology of Vector-borne Diseases (pp. 85-118). Oxford University Press.

# How will climate change affect vector-borne disease transmission?



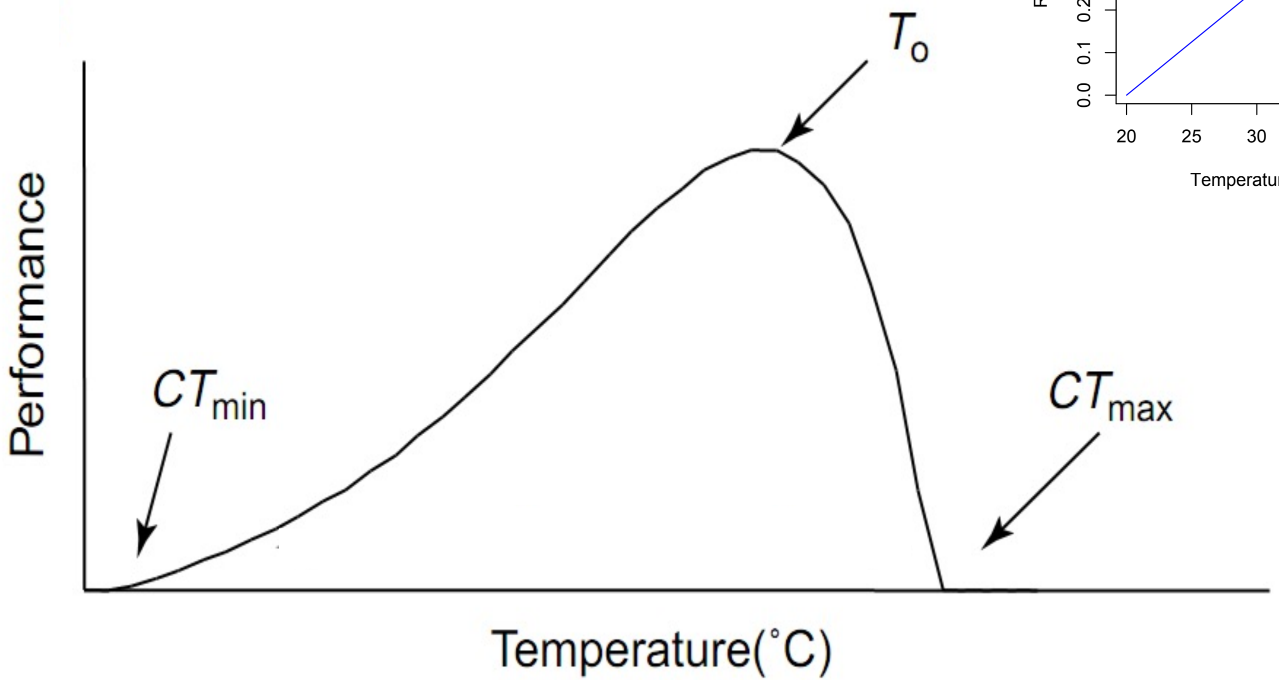
# "Warmer is sicker"

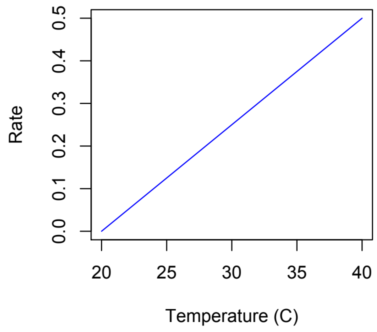



Epstein 2000

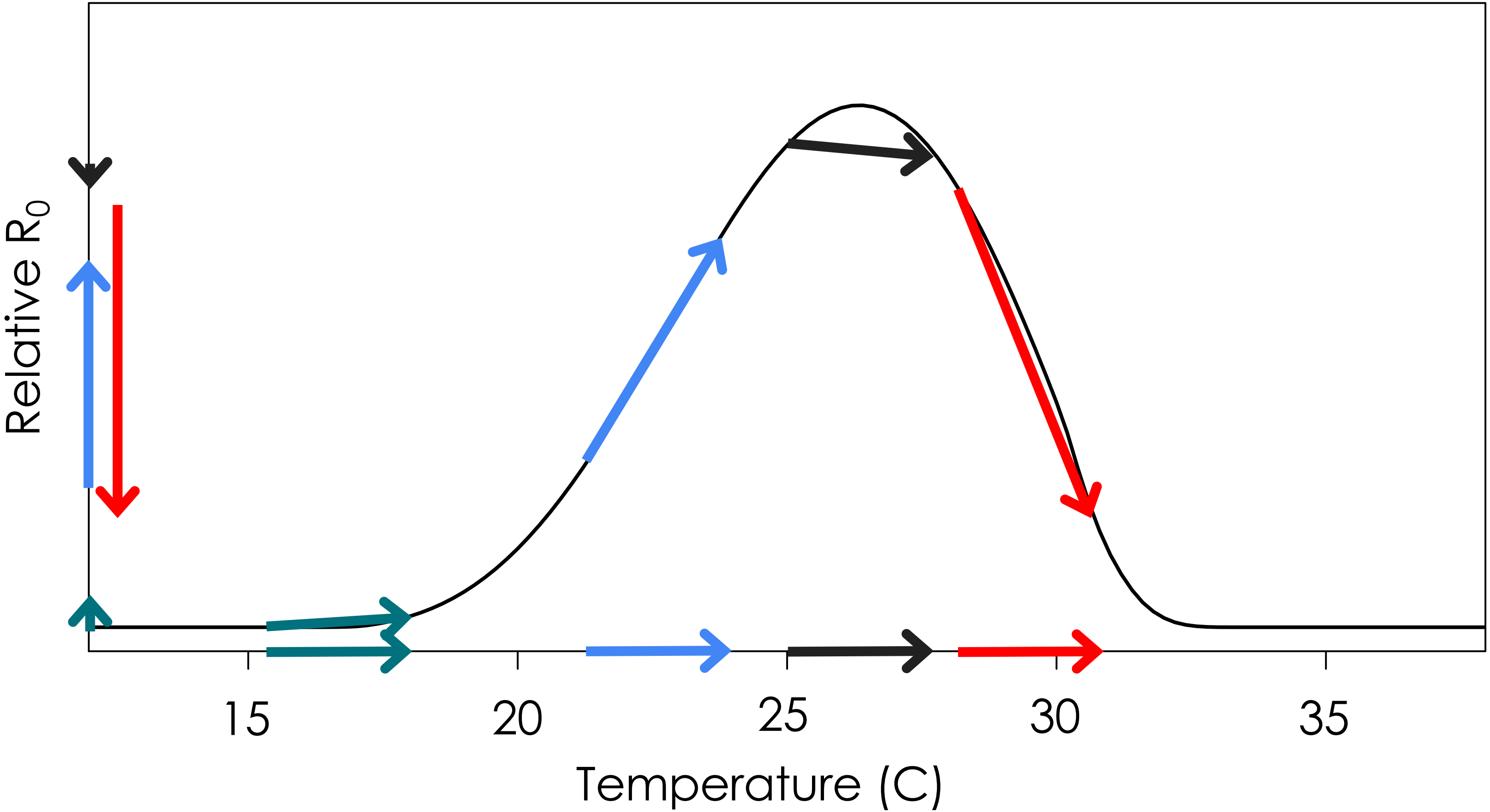
# Mosquito physiology



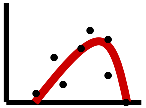

(Dell *et al*. 2011, Thomas & Blanford 2003, and many others)

# Global change & transmission suitability



# Our approach

Fit physiological responses with data



symmetric & asymmetric, linear (for comparison)

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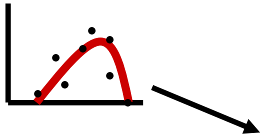
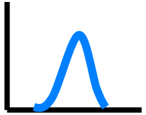


symmetric & asymmetric, linear (for comparison)

Calculate $R_0$ vs. temperature



$$R_0 = \sqrt{\frac{a^2 bcmp^T}{(-\ln p)r}}$$

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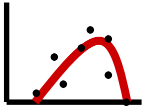

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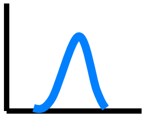
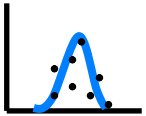


$$R_0 = \sqrt{\frac{a^2 bcmp^T}{(-\ln p)r}}$$

Validate
with
field data



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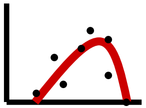

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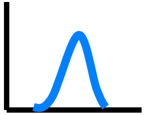

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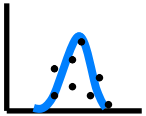
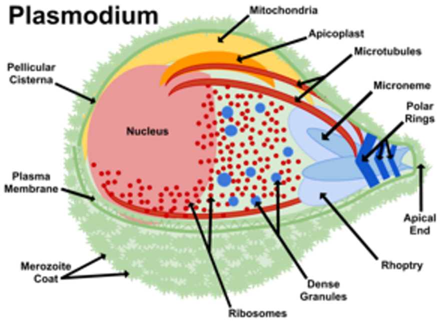


Project under future climate

# Temperature and Malaria


- Biting Rate
- Mosquito Infection Rate
- Transmission competence
- Parasite Development Rate
- Adult mosquito mortality rate
- Daily egg laying rate
- Egg to adult Survival
- Mosquito developmental rate

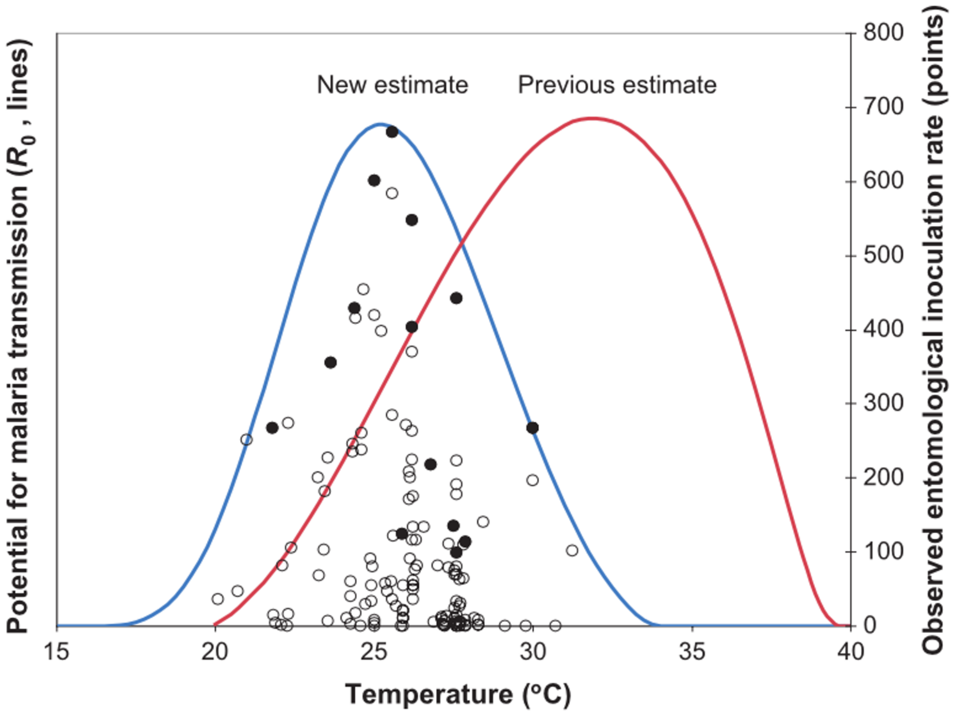
→ Temperature Dependent Processes

# Malaria and Climate Change

- Also complex:
  - Increased $CO_2$ concentration -> wetter soil moisture (less transpiration) -> increases *Anopheles* vector abundance
  - Increased temperature -> more rapid life cycle of *Anopheles* vector and the extrinsic incubation period of *Plasmodium* parasites
  - Reduced soil moisture with higher temperatures -> decreased larval habitats
  - It’s complicated!

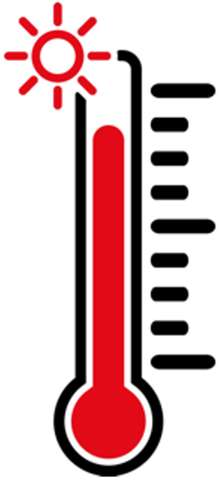
Phong Le et al. PLOS ONE, 2019

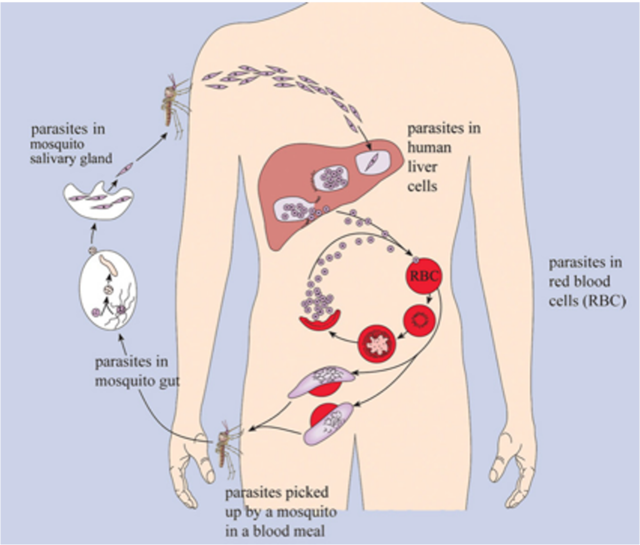
# Optimal temperature range for malaria lower than previously predicted



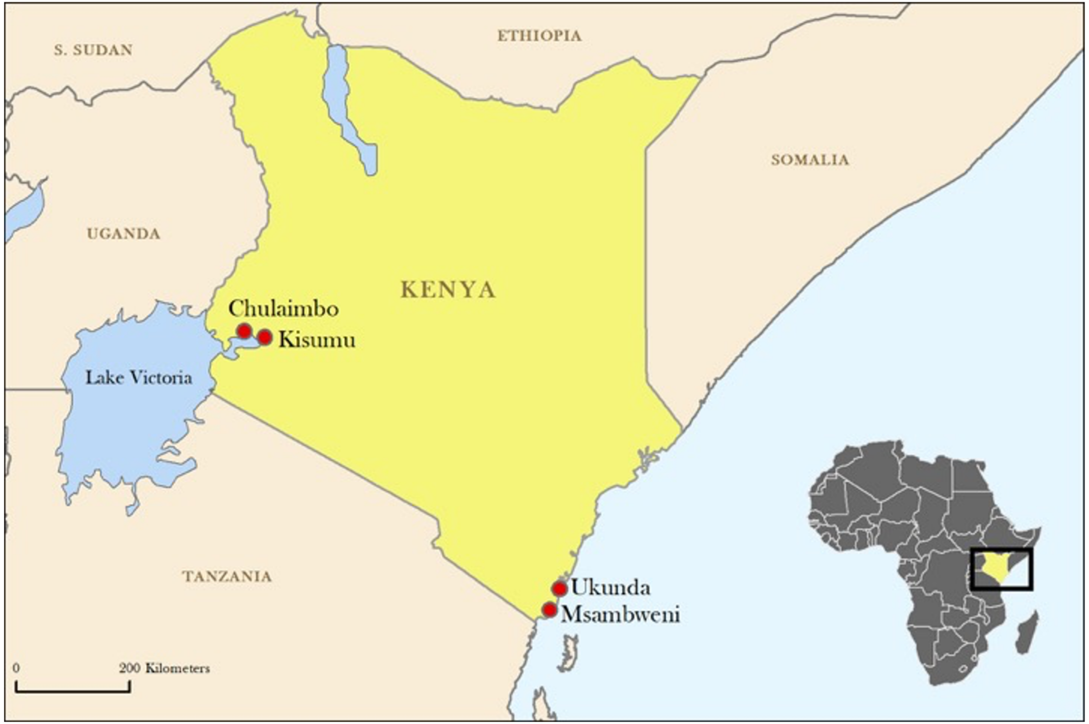

Mordecai, Erin A., et al. "Optimal temperature for malaria transmission is dramatically lower than previously predicted." *Ecology letters* 16.1 (2013): 22-30.

**Our study:** Is the temperature effect predicted by this ecological model applicable to clinical malaria incidence?





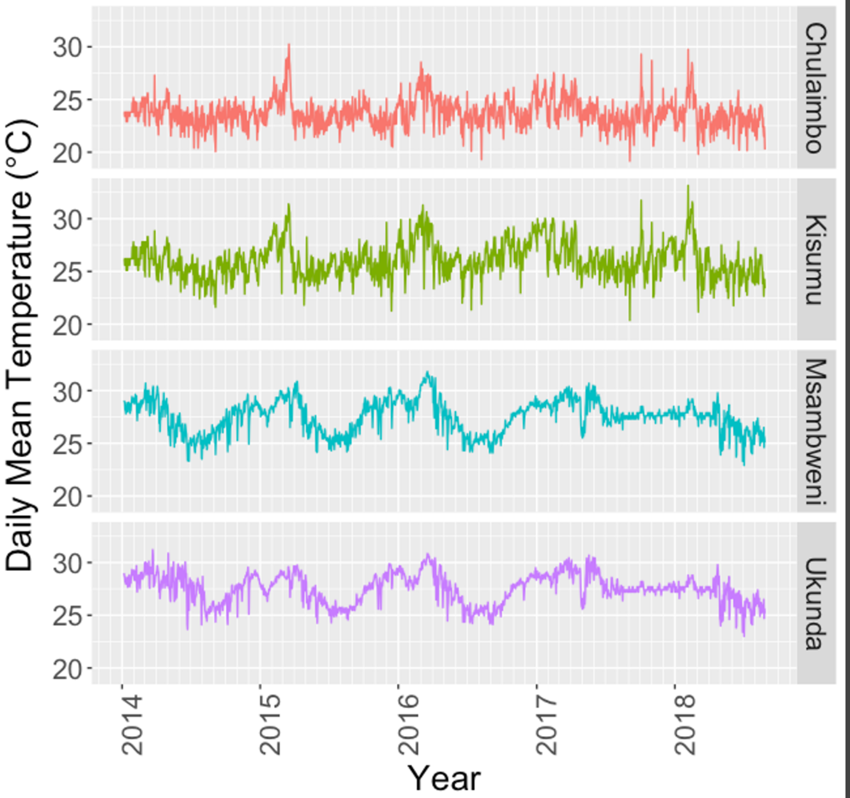
# Four Outpatient Sites in Kenya

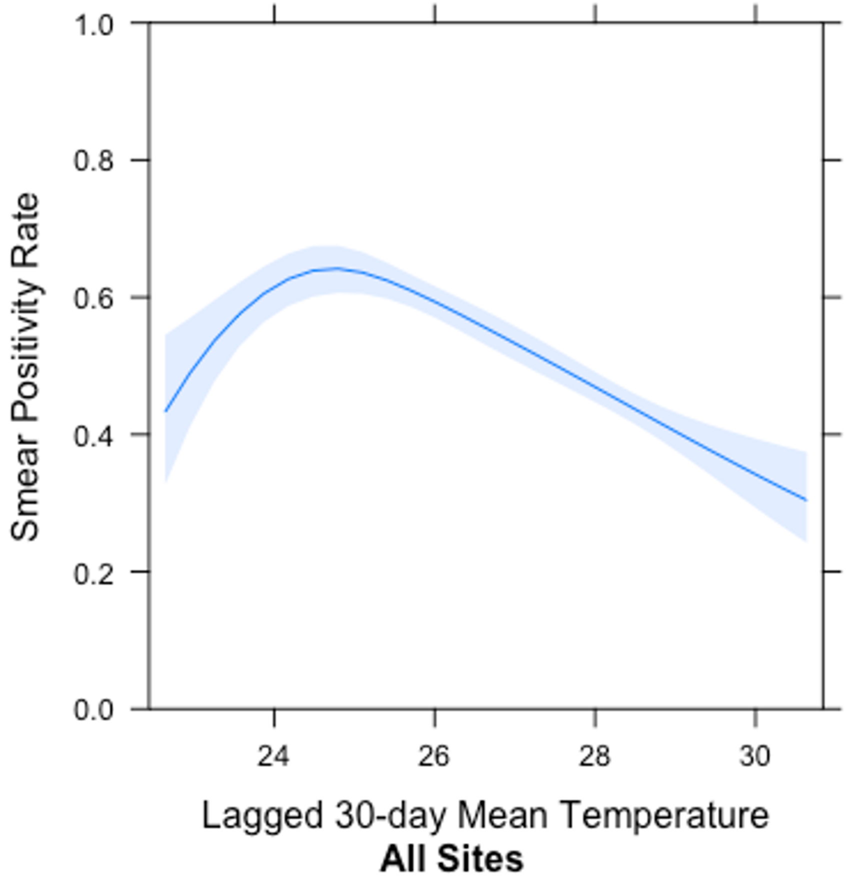



Temperature, Rainfall and Humidity measured daily

Children with Undifferentiated Febrile Illness **n=5,833**

# Malaria Smear Positivity and Temperature Ranges at the Four Sites

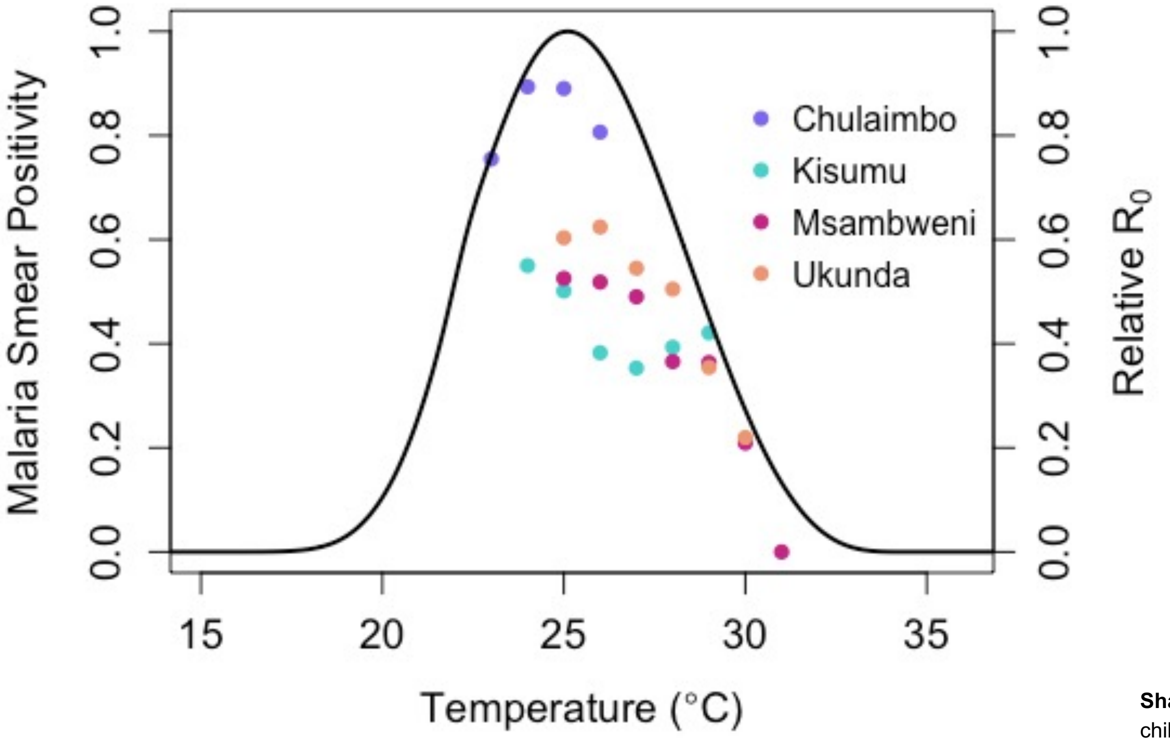



# Effect of 30-day Mean Temperature on Smear Positivity at Four Clinical Sites

*controlling for rainfall, bednet use, sex, age, socioeconomic status

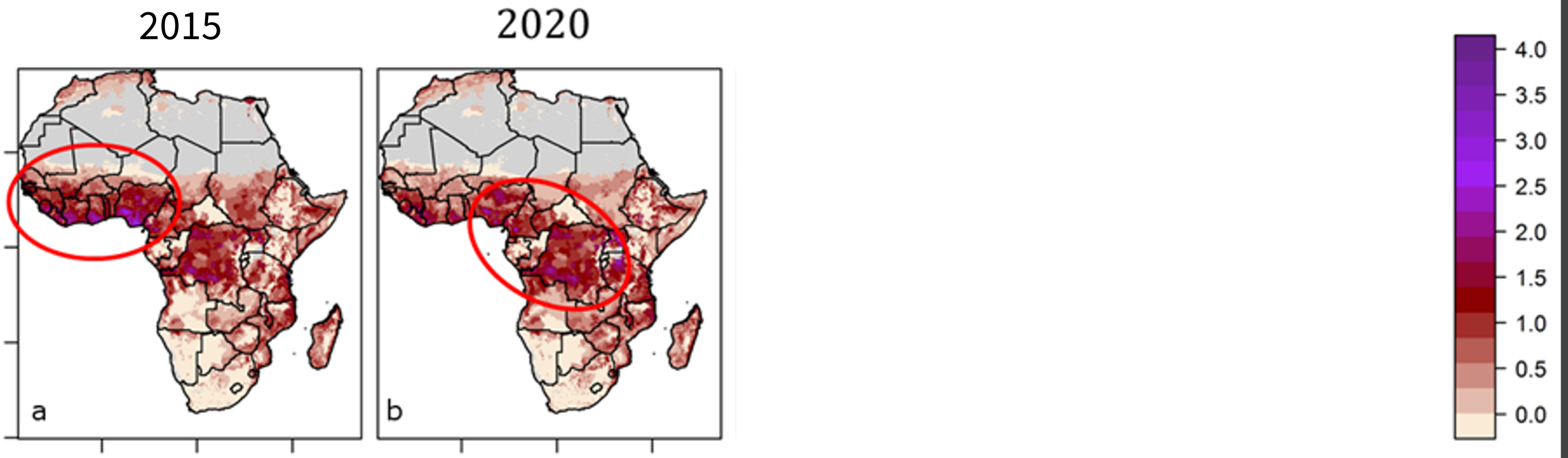
**Shah MM** et al.. Malaria smear positivity among Kenyan children peaks at intermediate temperatures as predicted by ecological models. *Parasites and Vectors*. 2019

# Malaria Smear Positivity plotted alongside Relative $R^o$ at Four Clinical Sites



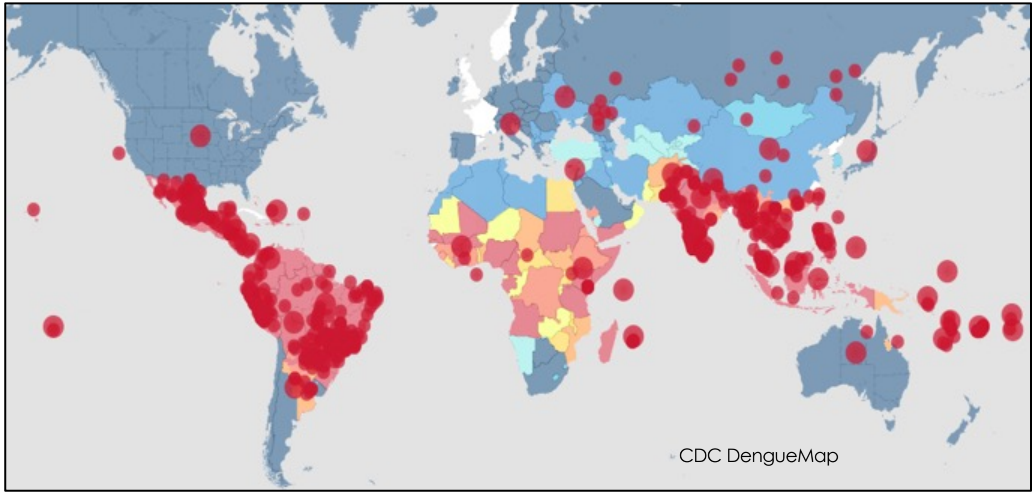

**Shah MM** et al.. Malaria smear positivity among Kenyan children peaks at intermediate temperatures as predicted by ecological models. *Parasites and Vectors*. 2019

# Climate change will shift **burden** of **malaria**




Ryan, Sadie J., et al. "Mapping physiological suitability limits for malaria in Africa under climate change." *Vector-Borne and Zoonotic Diseases* 15.12 (2015): 718-725.

# Dengue and Chikungunya

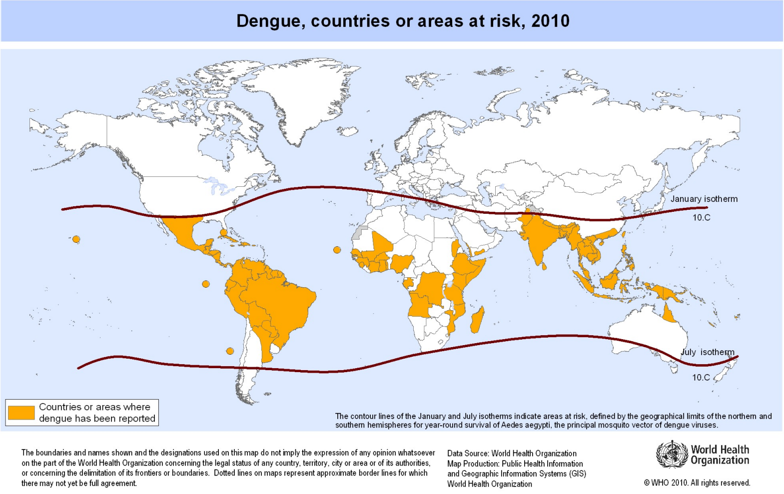



*Aedes aegypti*

*Aedes albopictus*

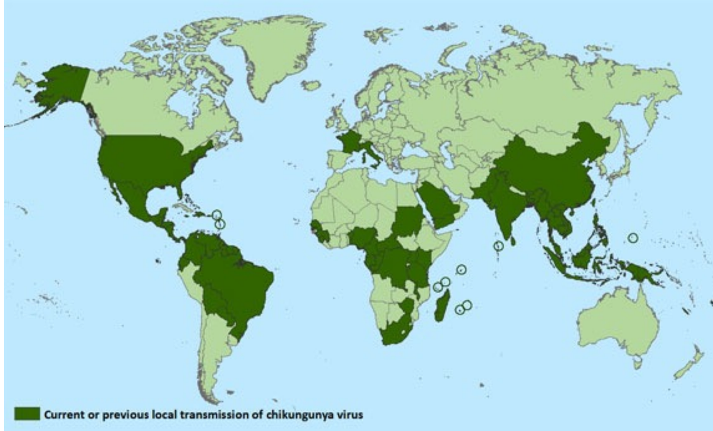
# Dengue

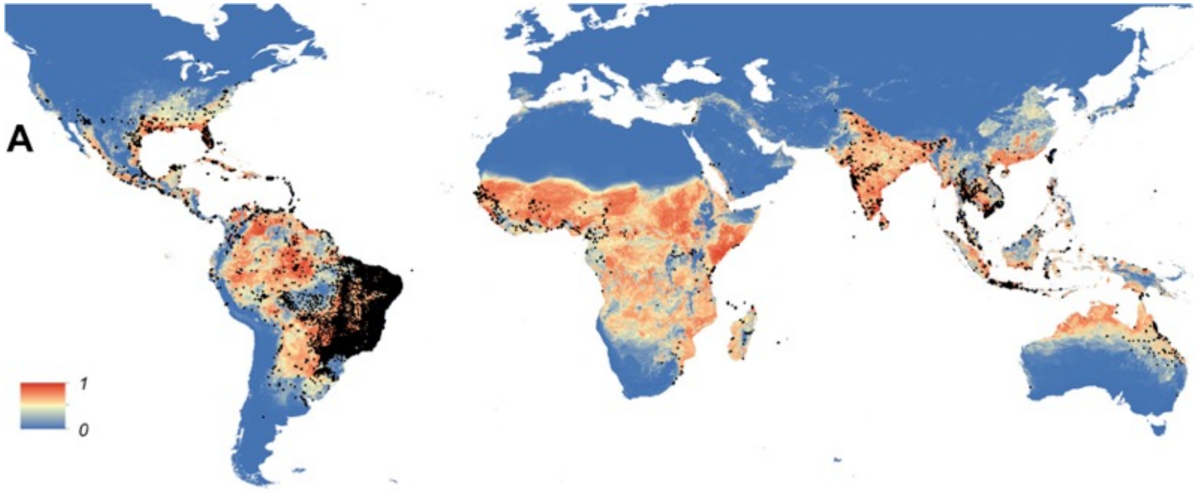
- 400 million infections worldwide yearly
- Four serotypes (DENV1-4)
- 4-7 days after an infected *Aedes* bite
- Fever usually over 40 deg C and rash
- Retro-orbital headache, generalized myalgias
- In some, progression occurs after resolution of fever and leads to capillary leak
  - Bleeding from the GI tract and shock
  - Often after second dengue infection
- No widely effective vaccine available

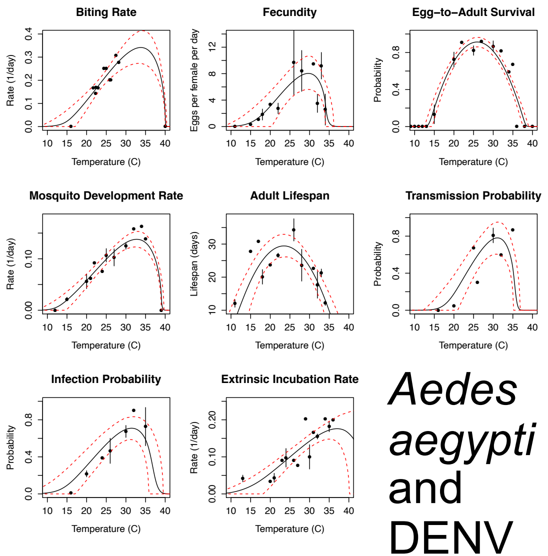



# Chikungunya

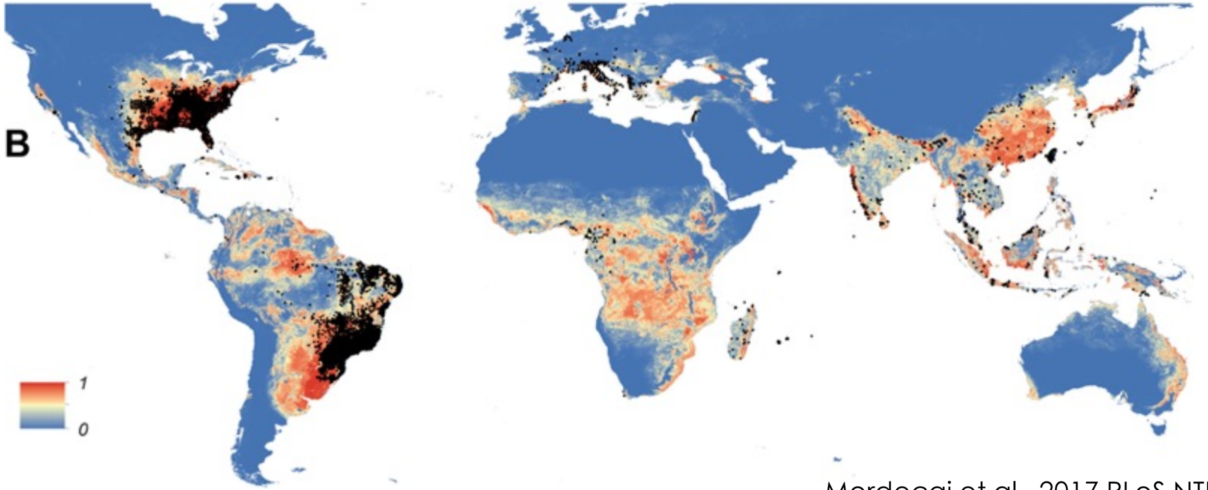
- 2-5 days after an infected *Aedes* bite
- Fever up to 40 deg C
- Petechial / maculopapular rash on trunk
- Arthralgia /arthritis of multiple joints
- Headaches, conjunctivitis, photophobia
- Fever lasts two days, but prostration/HA last 7 days
- Joint symptoms usually last weeks, but can last years

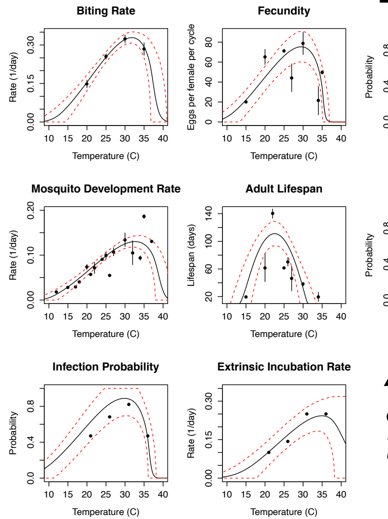



*Aedes aegypti* and DENV

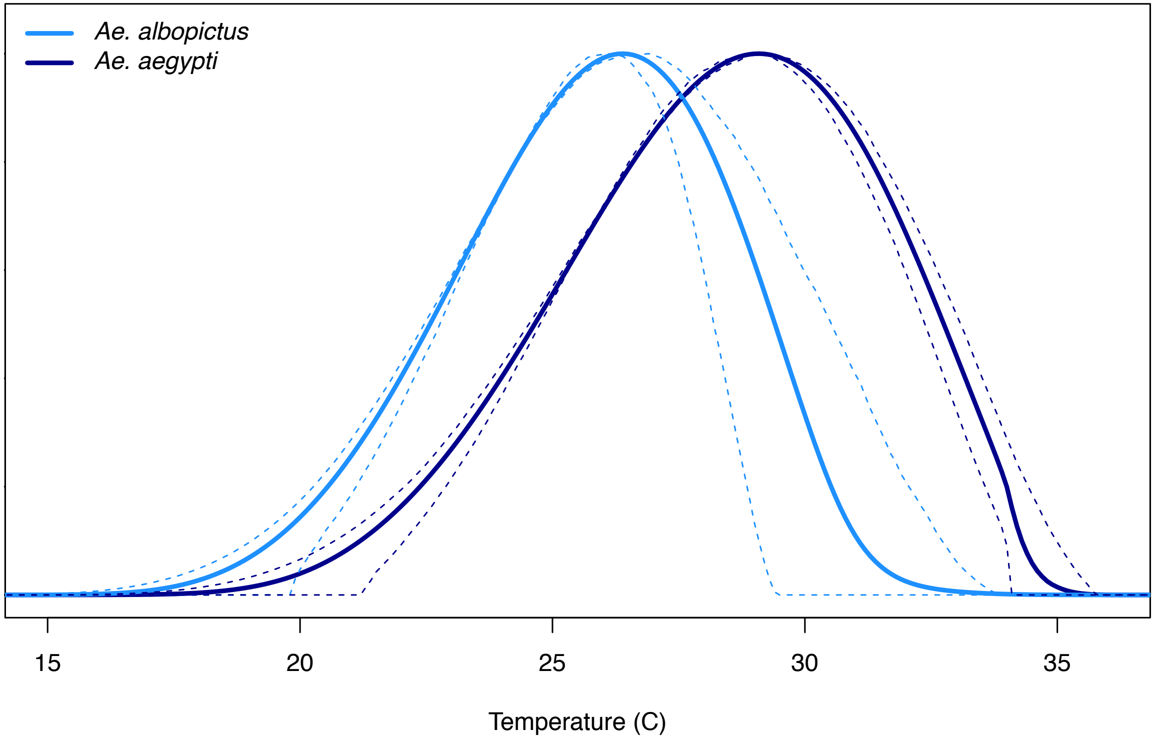



*Aedes albopictus* and DENV

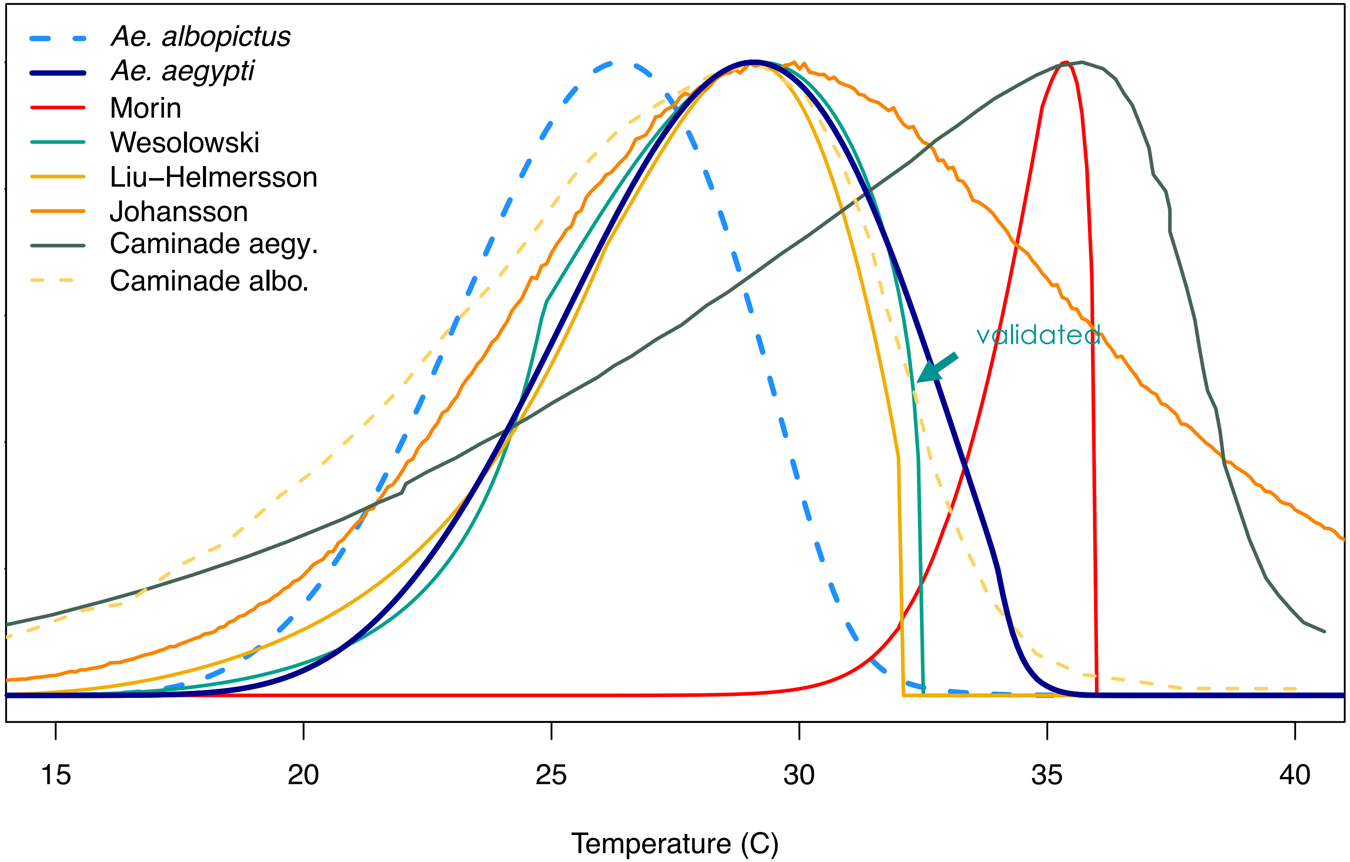
Mordecai et al., 2017 PLoS NTD

# $R_0$ for DENV, CHIKV, ZIKV



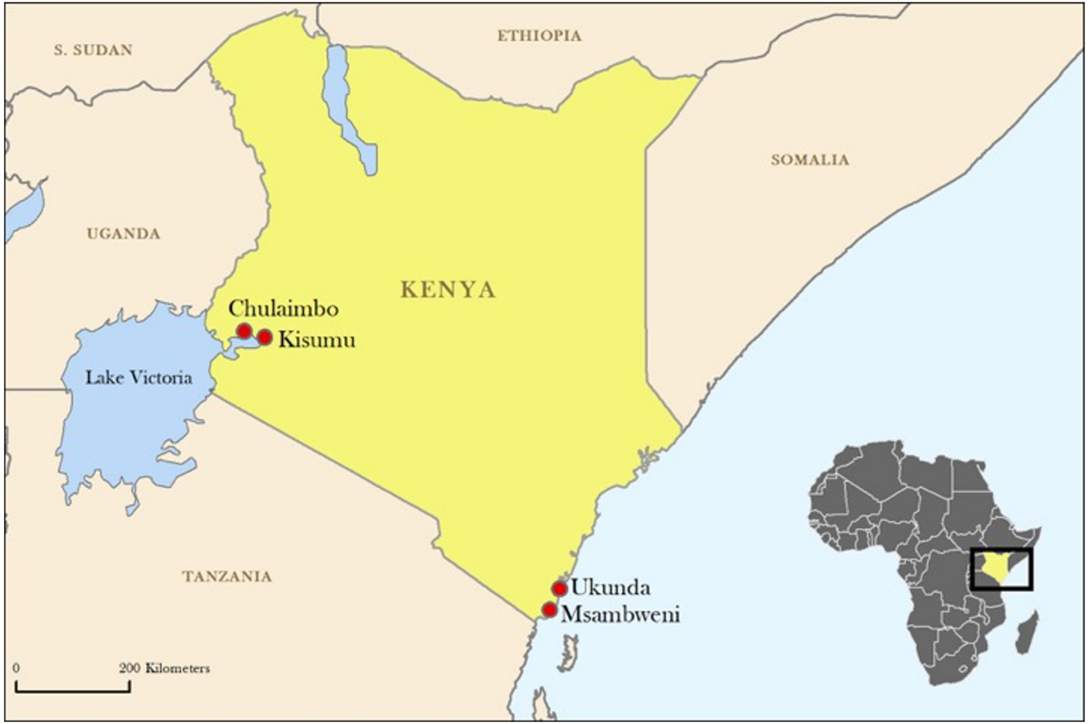

Mordecai et al., 2017 PLoS NTD

# Compared to previous models




Mordecai et al., 2017 PLoS NTD

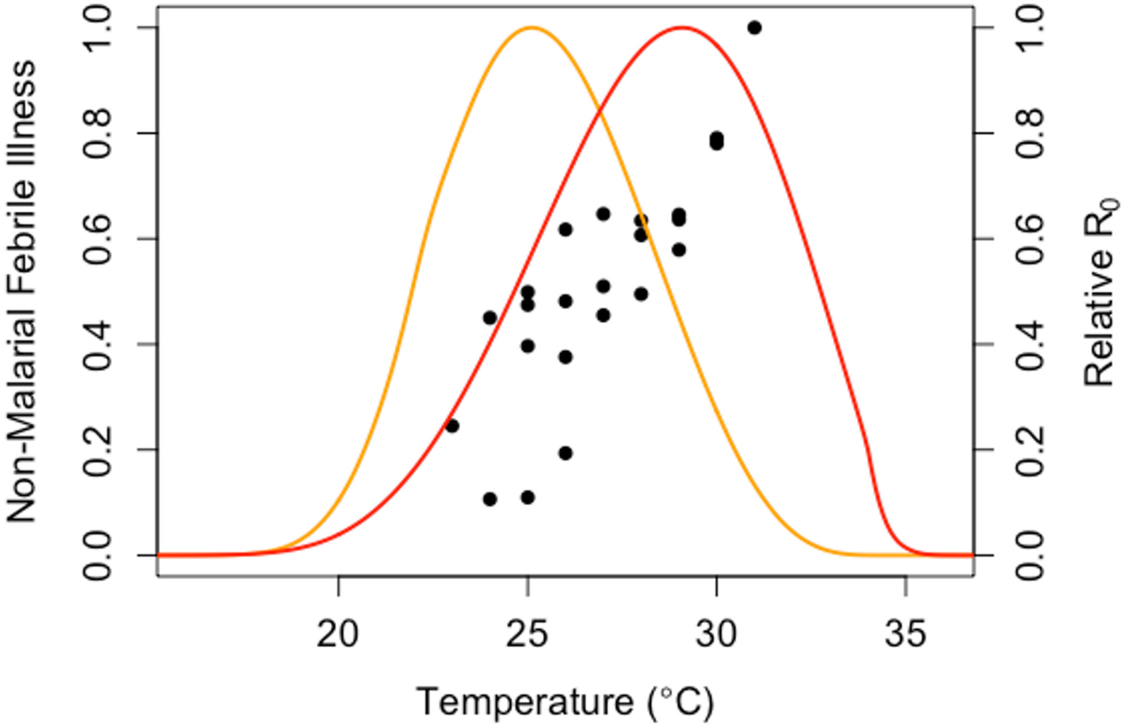
# Four Outpatient Sites in Kenya




Temperature, Rainfall and Humidity measured daily

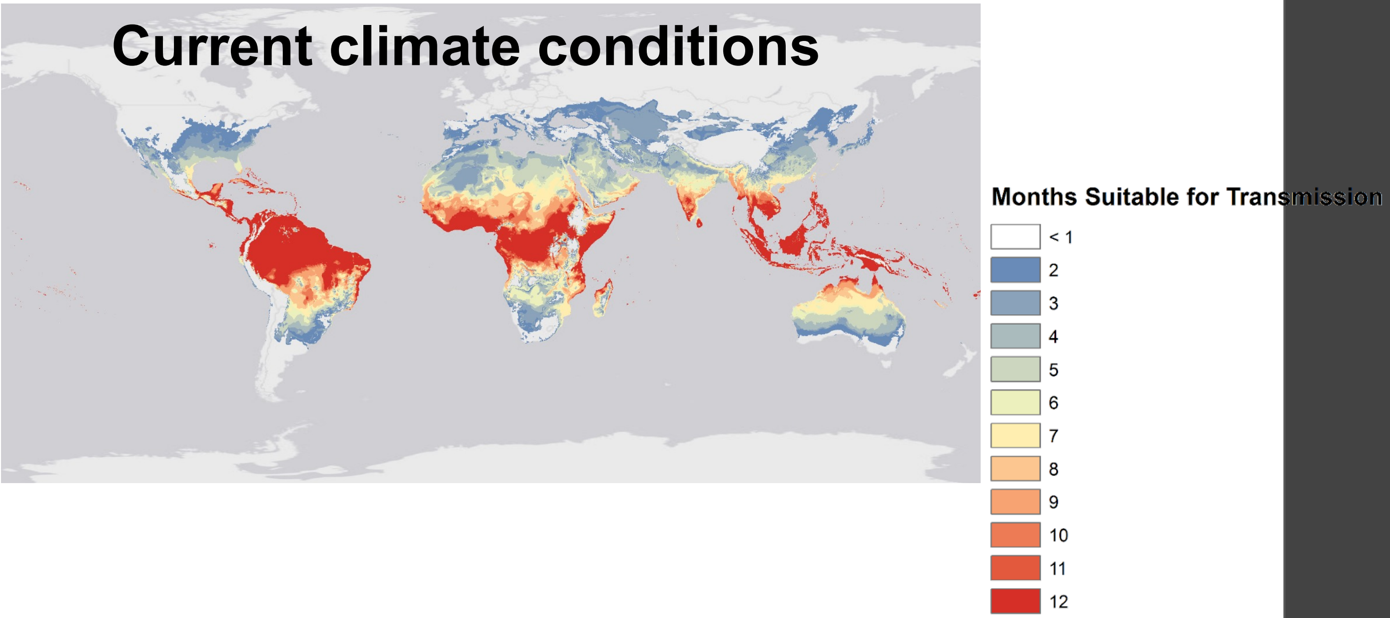
Children with Undifferentiated Febrile Illness **n=5,833**

# Non-Malarial Fever and Temperature



# WHEN AND WHERE IS CLIMATE SUITABLE FOR TRANSMISSION?

*Aedes aegypti*




Ryan et al
BioRxiv

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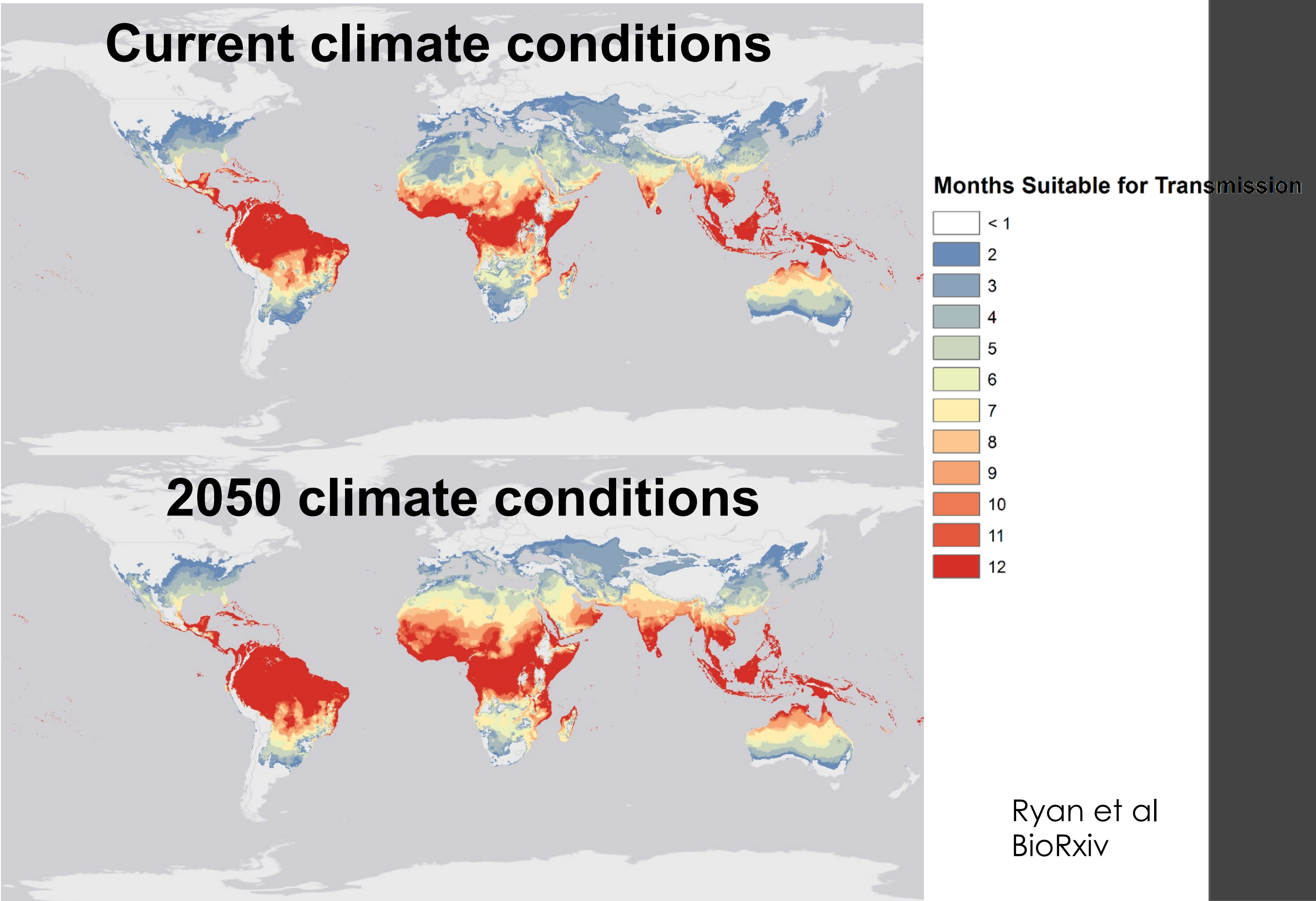
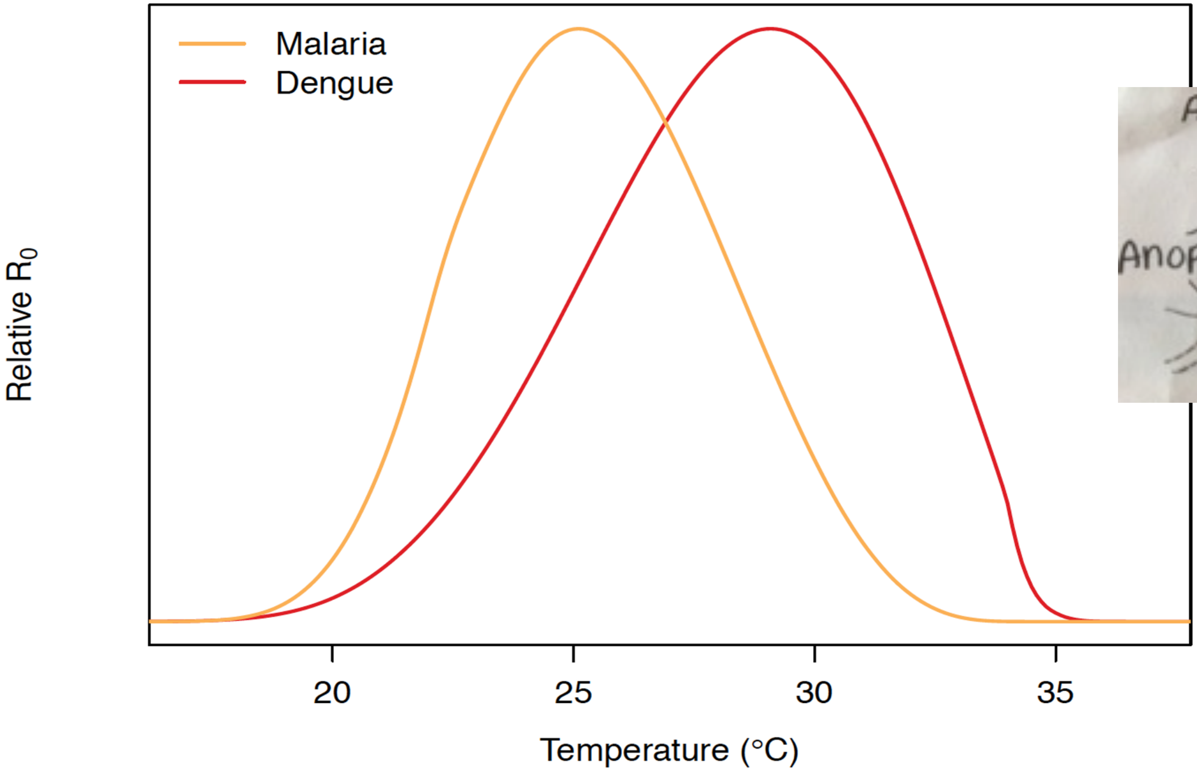



Ryan et al
BioRxiv

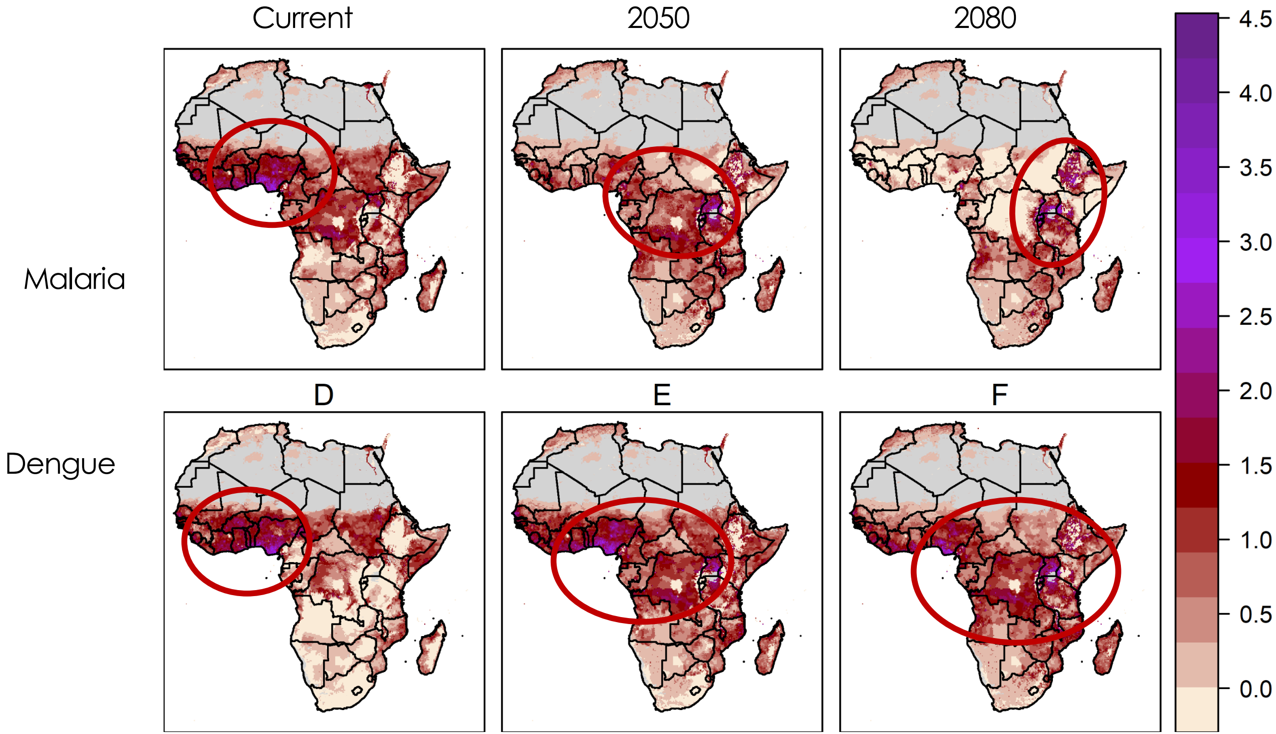
# Reproductive Number Curves for Malaria and Dengue Virus





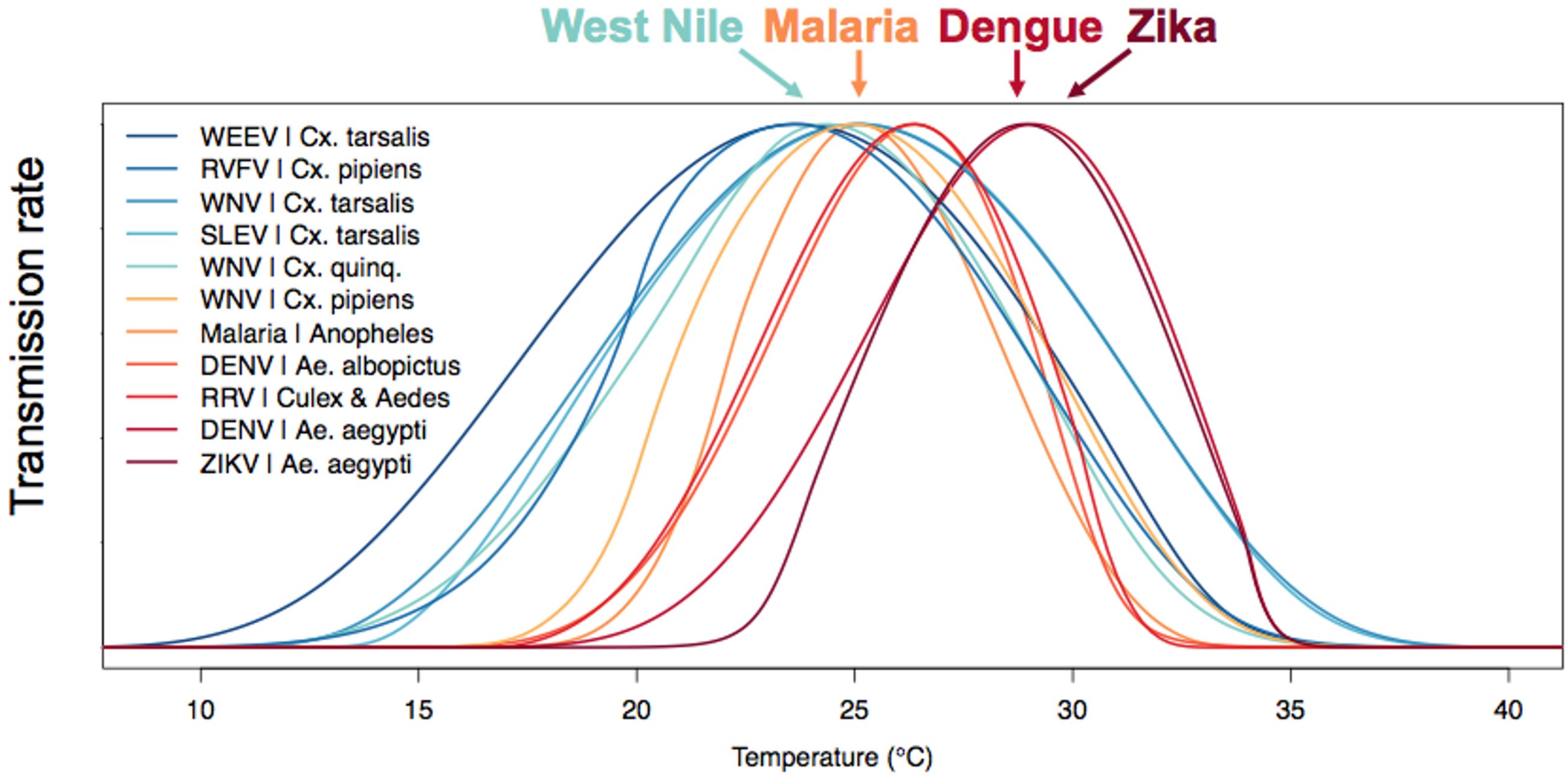
Mordecai EM, Sadie R, Caldwell J, Shah MM, LaBeaud AD. Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planetary Health, 2020.

# Climate change may drive a shift from **malaria** to **dengue** in Africa




Mordecai, Ryan, Caldwell, Shah, LaBeaud. Lancet Planetary Health, 2020

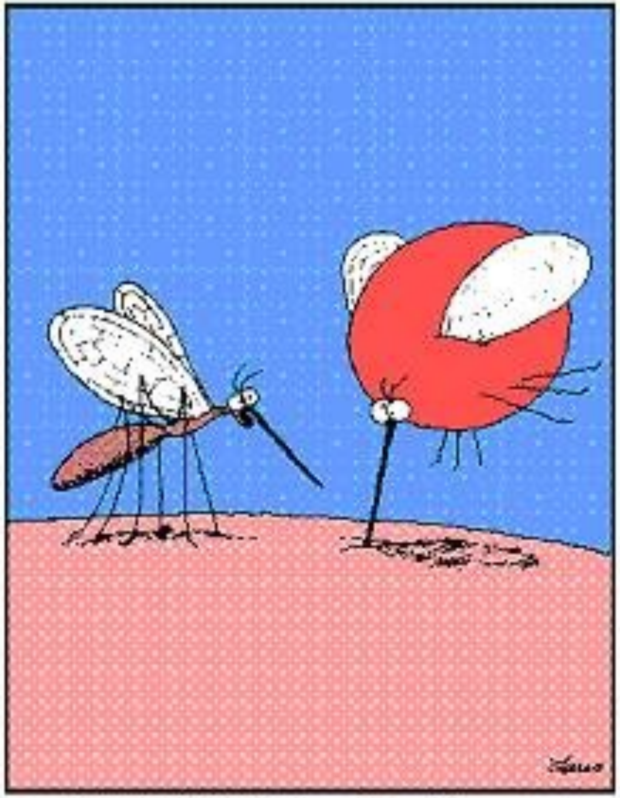
# Will climate change **shift** disease burden across the world?




Mordecai et al. 2013, 2017, Johnson et al. 2015, Shocket et al. 2018, in prep, Tesla et al. 2018

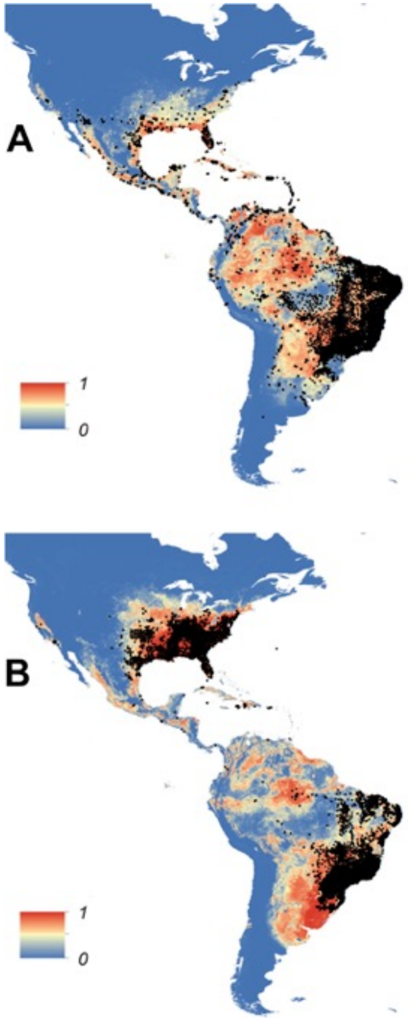
# Challenges FOR the world

- Non-immune populations
- Widespread competent mosquito vectors
- No rapid local testing currently
- Limited physician knowledge and clinical suspicion
- Poor diagnostics
- No treatments or vaccines

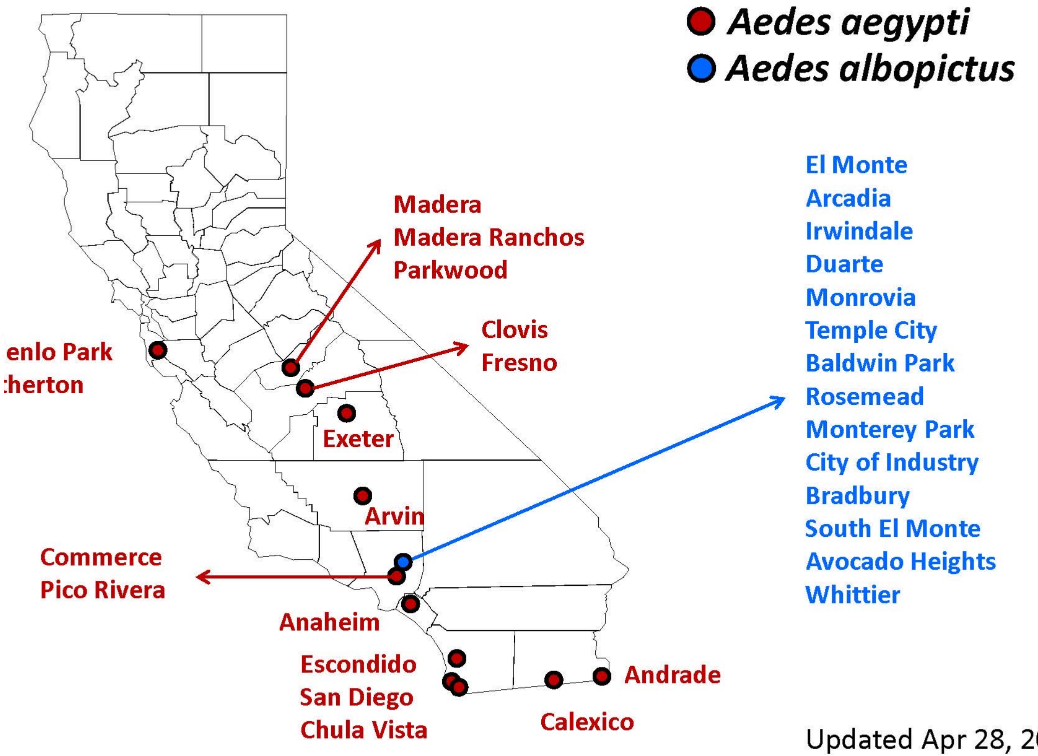


"Pull out, Betty! Pull out! . . . You've hit an artery!"

# ypti at my home



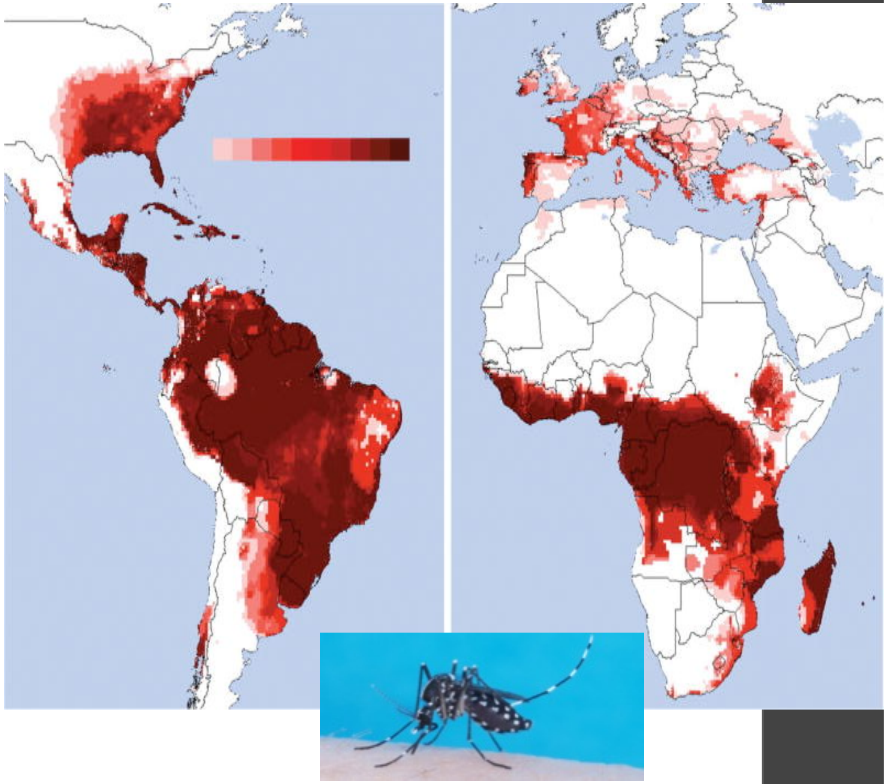

## des aegypti and Aedes albopictus Mosquitoes Detection Sites in California, 2011-2015




Updated Apr 28, 2015

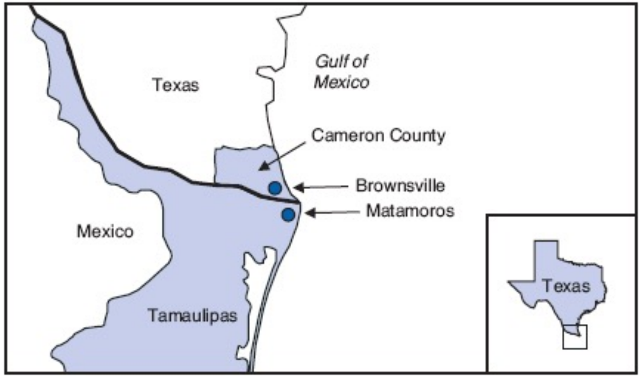
# Spread of the Asian Tiger Mosquito: *Aedes albopictus*

- Tropical species – Warm weather enhances survival, reproduction, and spread
- Drought - unintended consequence – Residents store water in backyard buckets, containers, and rain barrels
- *Aedes* establishment and spatial distribution may serve as indictors of climate change



Spread of the Tiger: Global Risk of Invasion by the Mosquito *Aedes albopictus*
*Vector Borne Zoonotic Diseases 2007:7(1):76-85*

# Spread of Dengue in US

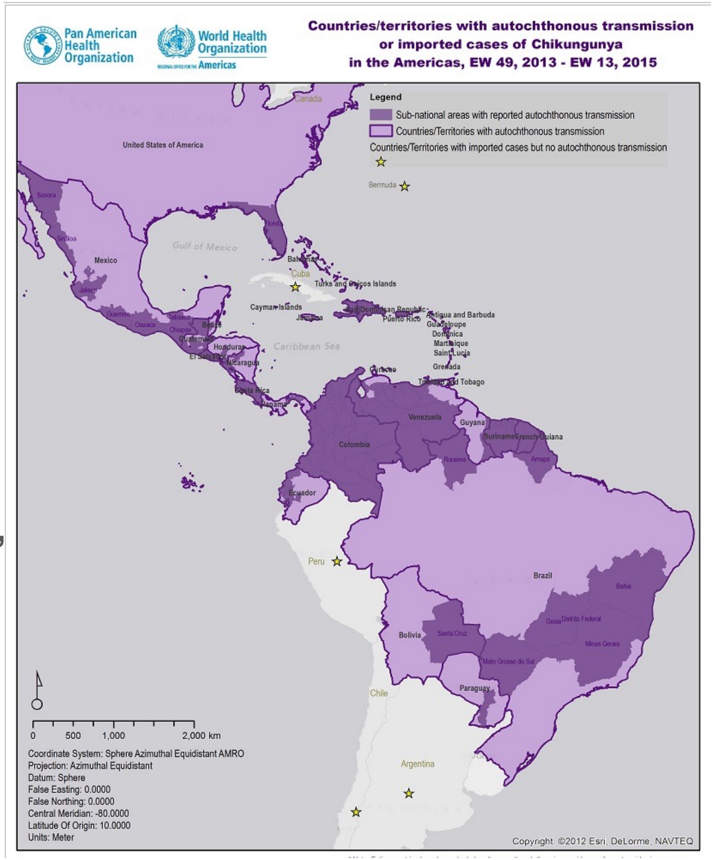

- Laredo, TX: 1999
  - 50% had undiagnosed dengue infection
- Brownsville, TX: 2005
  - Autochthonous spread
  - 38% seropositive
- Key West, FL: 2009-2010
  - First cases outside TX since 1945
  - Locally acquired
- 2013: South Texas, Florida
  - **Long Island, NY**
    - One locally acquired case

CDC. MMWR. Aug 2007.

# April 2015

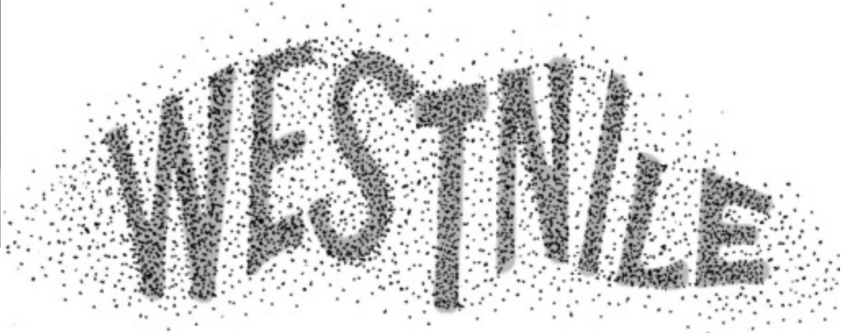
## Countries in the Americas where chikungunya cases have been reported:

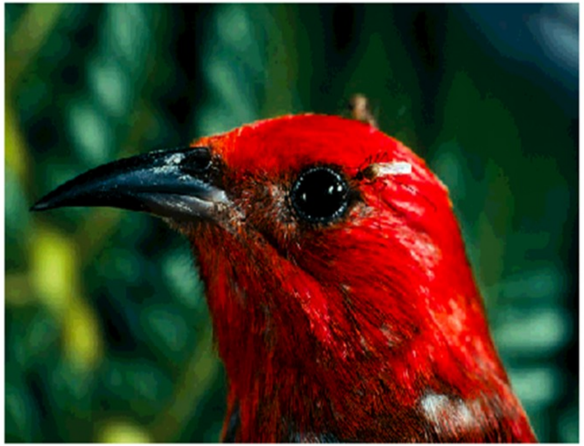
**Mexico, Belize, Brazil, Colombia, Honduras, Costa Rica, Colombia, El Salvador, Ecuador, French Guiana, Guatemala, Guyana, Nicaragua, Panama, Paraguay, Suriname, Venezuela**




Countries and territories in the Americas where chikungunya cases have been reported:

Anguilla,
Antigua and Barbuda,
Aruba,
Bahamas,
Barbados,
British Virgin Islands,
Cayman Islands,
Curacao,
Dominica,
Dominican Republic,
Grenada,
Guadeloupe,
Haiti,
Jamaica,
Martinique,
Montserrat,
Puerto Rico,
Saint Barthelemy,
Saint Kitts and Nevis,
Saint Lucia,
Saint Martin,
Saint Vincent and the Grenadines,
Sint Maarten,
Suriname,
Trinidad and Tobago,
Turks and Caicos Islands,
US Virgin Islands


WESTNILE




WHAT THE?
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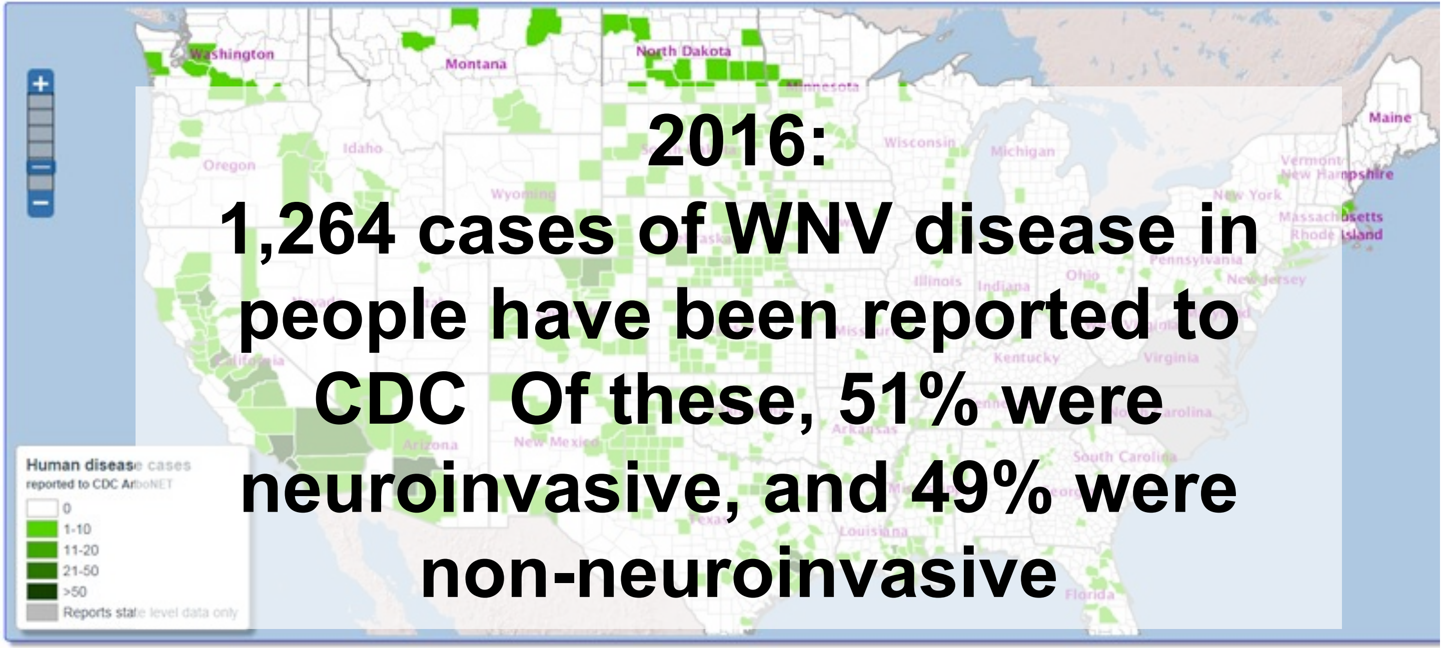
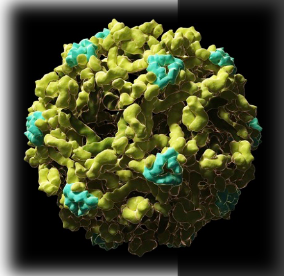
# West Nile virus

- Most common arbovirus in the US
- Vector: *Culex* mosquitoes
- Geographical Distribution




**2016:**

**1,264 cases of WNV disease in people have been reported to CDC Of these, 51% were neuroinvasive, and 49% were non-neuroinvasive**

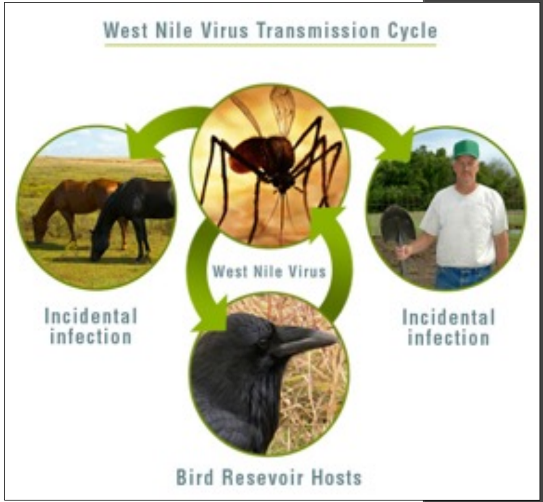


# West Nile virus

- Clinical and laboratory diagnosis:
  - Fever, headache, malaise, back pain, myalgia, and anorexia
  - Eye pain, pharyngitis, nausea, vomiting, diarrhea, and abdominal pain
  - Acute symptoms typically last 3 to 10 days, but some patients with WN fever report a prolonged recovery to their previous baseline functioning
- Neuroinvasive disease:
  - Fever, headache, meningeal signs, and photophobia
  - Encephalitis ranges in severity from a mild, self-limited confusional state to severe encephalopathy, coma, and death
  - Polio-like illness

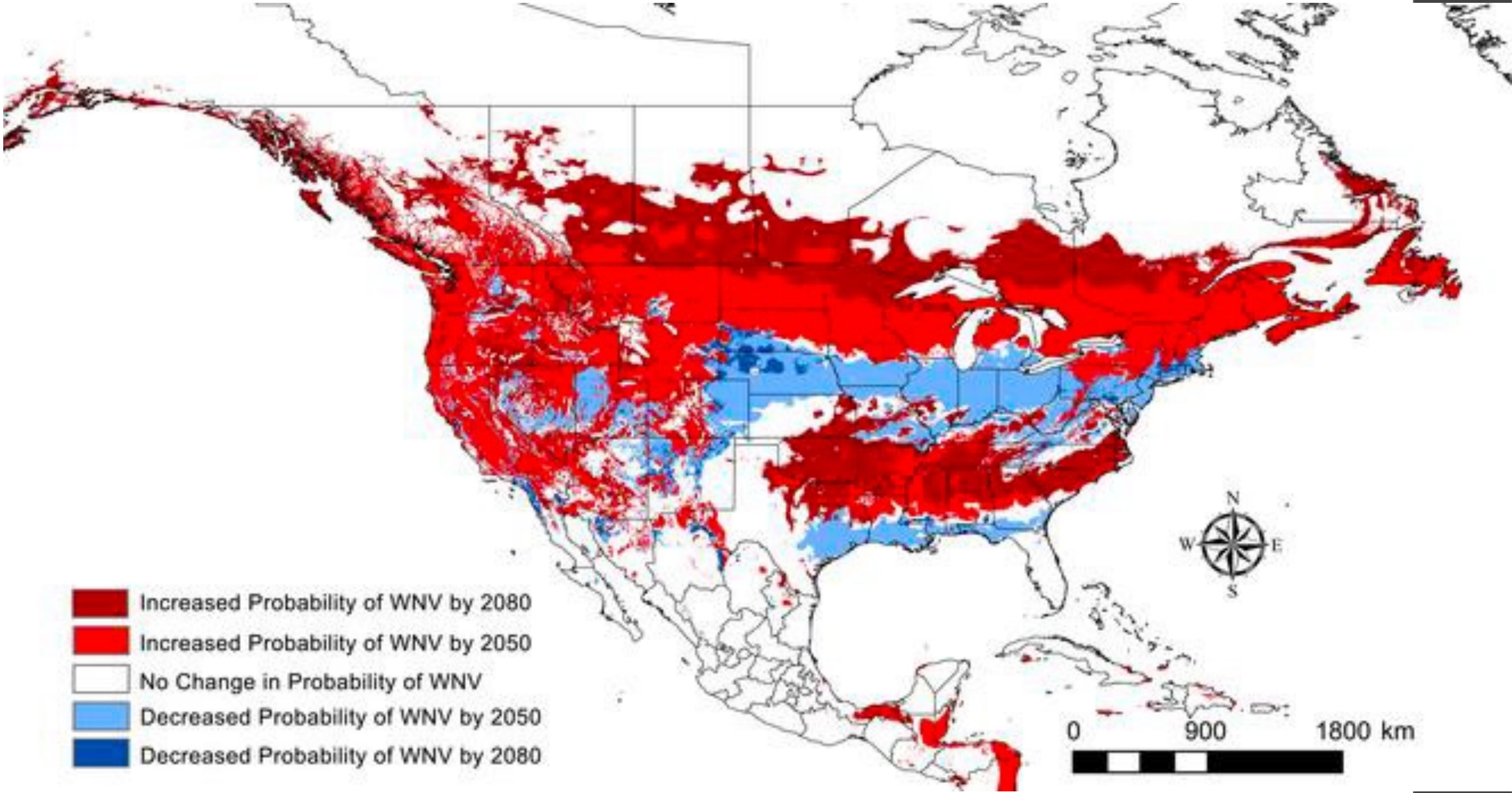
# West Nile and Climate Warming

- Many factors influence the level of West Nile virus activity
  - Climate: temperature, precipitation
  - Mosquito abundance and type
  - Number and types of avian reservoir hosts
    - Level of immunity
- Hot temperatures = increased WNV activity
  - Increase mosquito development rate (egg to adult) so greater population size
  - Increase viral replication rate within the mosquito
  - Increase the speed the virus reaches the salivary glands
  - Increase the speed mosquitoes digest blood so they feed more often (thus spreading infections more quickly)
- Warm spring temperatures prompt early season mosquito activity and a longer virus amplification period



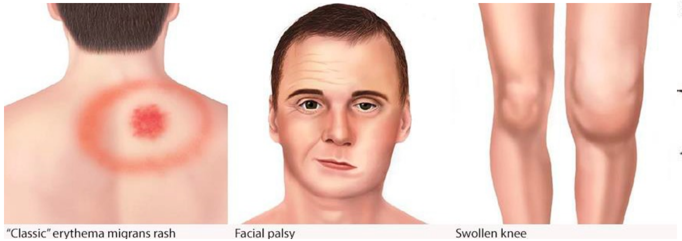
# West Nile and Rainfall

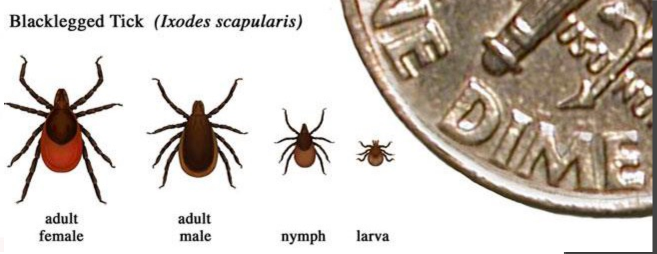
- Complex relationship
- *Culex* mosquitoes need pools of standing water to breed and develop, but too much rainfall can wash away the developing mosquitoes
- Drought has been associated with increased WNV activity (2014)
  - Prevents the “washing out” of underground mosquito populations in urban wastewater systems or other water sources
  - More stagnant water sources earlier in mosquito “season”
  - May force birds and mosquitoes into closer proximity as both seek out limited sources of water, especially in urban areas, resulting in virus amplification



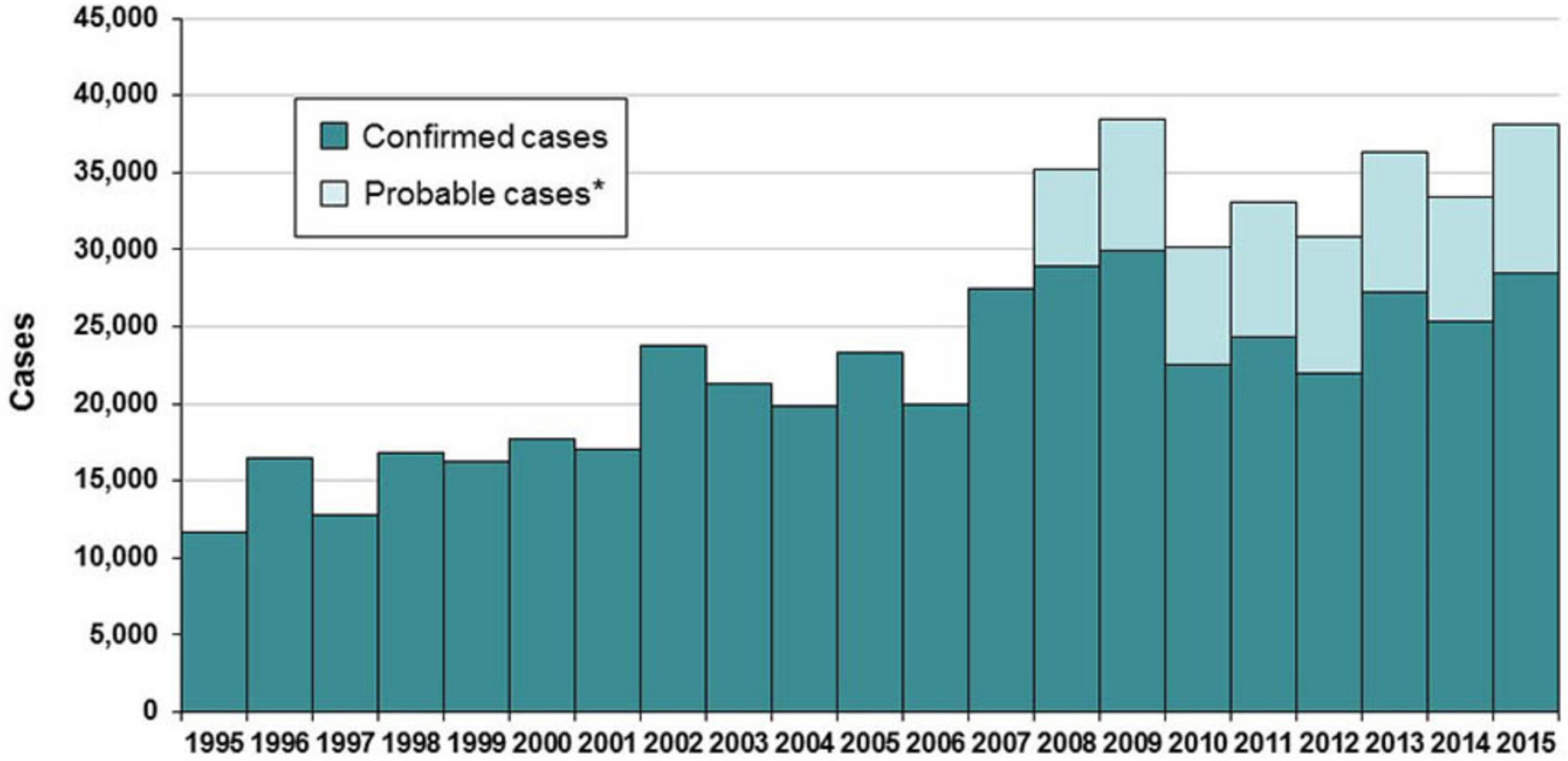

Harrigan et al. Global change biology. 2014

# Lyme Disease




- Caused by the spirochete bacteria *Borrelia burgdorferi*
- Transmitted by *Ixodes scapularis* (East) and *Ixodes pacificus* (West)
- Early Signs and Symptoms (3-30 days post tick bite)
  - Fever, chills, fatigue and erythema migrans rash in 70-80% patients.
- Later Signs and Symptoms (days to months post tick bite)
  - Multiple EM rashes, meningitis, Bell's Palsy, carditis, arthritis
- In the US, the incidence of Lyme disease has doubled since 1991, from about four cases per 100,000 people to eight per 100,000 people (300K cases per year)
  - Peaks in May through July when ticks are most active
  - >90% of Lyme cases in the Northeast, Upper Midwest, and mid-Atlantic; however, the number of counties that are now deemed high-risk for Lyme has increased >320% since the late 1990s

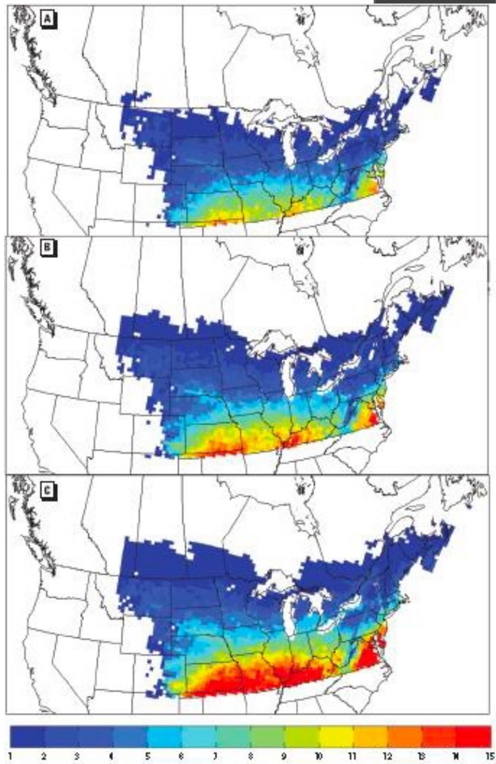


Confirmed cases
Probable cases*
Cases
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015


CDC

# Lyme Disease and Climate Change

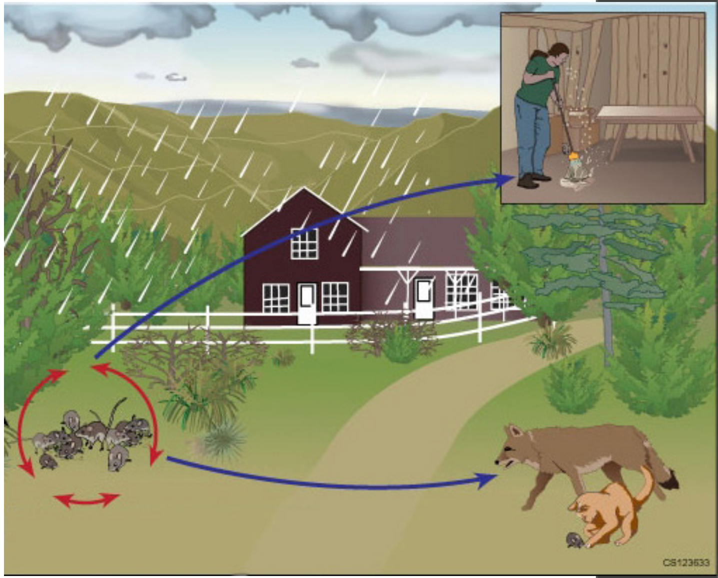
- Climate is one reason (along with deer population surges, land use change, and human behavior)
- Tick distribution is affected by temperature, rainfall, and humidity
    - Tick abundance is greatest in moist, humid environments and declines during hot, dry periods
    - Warmer temperatures can also increase the developmental rate of ticks
- With global warming, tick populations can move farther north, expanding their range and increasing the length of tick season
- Tick numbers may also be affected by abundance of animal hosts, such as rodents (acorns!) and deer (hunting limits), which in turn are affected by climate




Ogden et al. EHP, 2014.

# Hantavirus and Climate Change

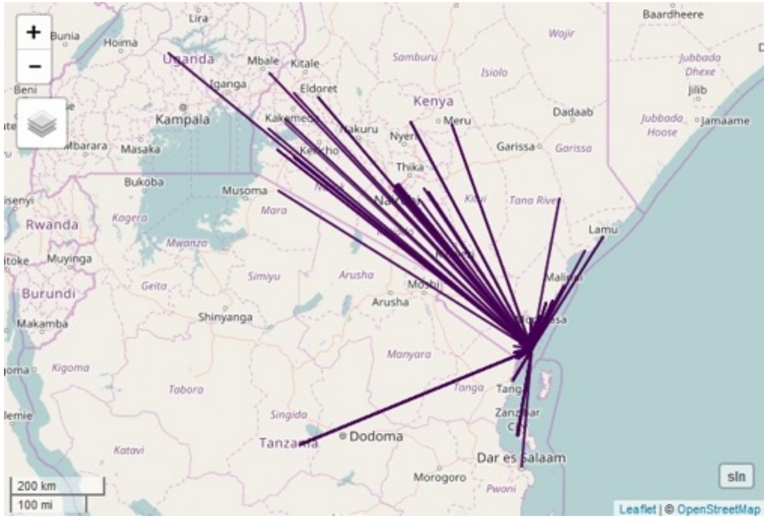

- Deer mice transmit Sin Nombre virus, the causative agent of hantavirus pulmonary syndrome (HPS)
- Climate affects the food and water supply for deer mice
- Deer mice populations typically increase when vegetation is abundant (mild winters and wet summers), often the year after above average precipitation
- Climate change may affect the distribution and abundance of deer mice which could alter hantavirus transmission risk



# Prevention

- Avoid mosquitoes
  - Repellents: DEET, Picaridin, Permethrin
  - Barriers: Wear long-sleeved shirts and long pants
  - Household design: Use A/C and/or intact window screens
- Vector control
  - Household level
    - Source reduction (Habitat removal)
  - Community level
    - Habitat removal, Larviciding, Adult spraying

# Human Behavior Matters!




# Climate change and health inequities

- Neglected People, Neglected Diseases
- NTDs = infectious tropical diseases in developing countries that are poverty-promoting and long-lasting
- Vector-borne diseases affect the impoverished more severely and promote poverty by causing long-lasting sequelae
- Climate change will exacerbate many health and social inequalities, while the impacts of VBDs will be disproportionately borne by vulnerable communities
- Those who work/play outside are more at risk:
    - Farm workers, children, women

LaBeaud AD. PLoS NTDs. 2008.

# Arboviruses in Children

- Imprecise estimates of disease burden
    - Requires both hospital and community surveillance
- Children of all ages are at risk for arboviral infection
- Few long-term sequelae studies so the full impact is not known
    - Cognitive deficits
    - Ocular complications

Recognition of the long-term sequelae of arboviral disease in childhood could unmask a substantial burden of disease

# Mitigating Vector-Borne Diseases

- Infrastructure
  - Sustained vector control efforts are important to prevent outbreaks
- Address research gaps
  - Better diagnostics, Vaccines, Targeted therapeutics
- Disease tracking
  - Develop optimal scientific approaches to understanding the many factors associated with climate change and infectious diseases
  - Improve the prediction of the spatial–temporal process of climate change and the associated shifts in infectious diseases at various spatial and temporal scales
  - Establish locally effective early warning systems for the health effects of evolving climate change

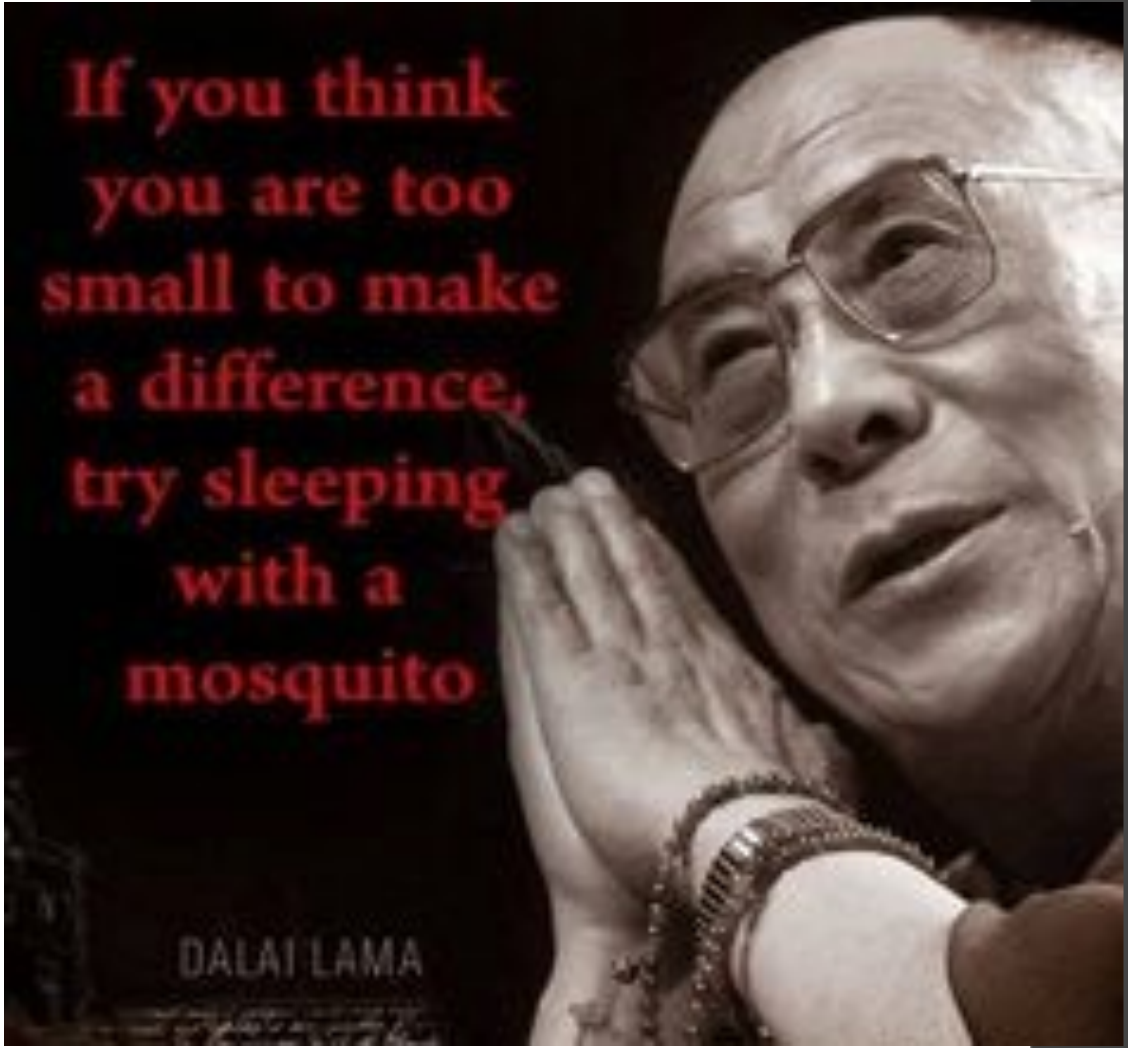
# What can health professionals do?

- Uniquely poised to promote resilience to climate-related stressors, recognizing that not all individuals and communities are impacted equally by climate change
- Recognize that disease vectors and diseases are expanding their range
- Stay curious and open to new diagnoses
- Investigate patient risk and take time for participatory guidance during visits
- Stay in contact with board of health and vet professionals
- Work with public health and climate science communities to build climate resilience while planning VBD prevention and response activities at the community level
- Apply a health equity lens to the framing, understanding, and quantifying of the co-benefits of climate resilience action, to promote local, state, and national policymaking that simultaneously improves health and reduces health inequities

# Conclusions


- Climate is important for determining where and when conditions are suitable for transmission
- Climate change will exert a nuanced effect on vector-borne disease transmission depending on location and health equity
- Climate affects vector-borne diseases and will alter their distribution and occurrence
- Climate change may promote a shift from malaria to arboviruses in many parts of sub-Saharan Africa
- Surveillance and education are critical to monitor changing patterns and mitigate public health risk
- Disease incidence in vectors, reservoirs, and humans may serve as potential indicators of climate change
- Health care professionals are poised to protect patients and promote climate resilience especially among vulnerable groups

Thank you for your attention!



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