Climate Change and Health:

Vector-borne Diseases

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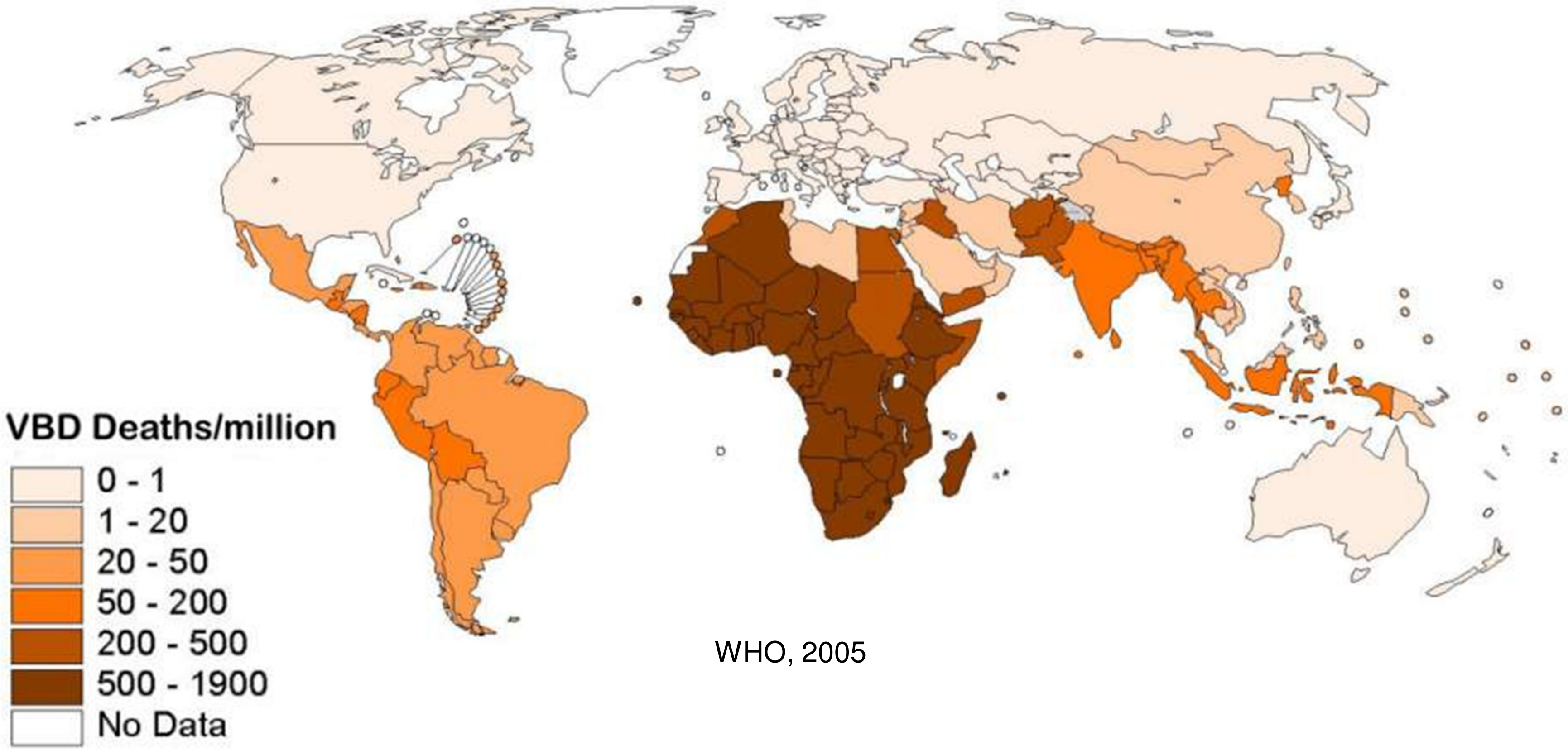
Vector-borne Disease Mortality Global Distribution



WHO, 2005

- **Majority of Vector-borne Disease (VBD) burden borne by developing countries**
- **Disproportionate amount in Africa**

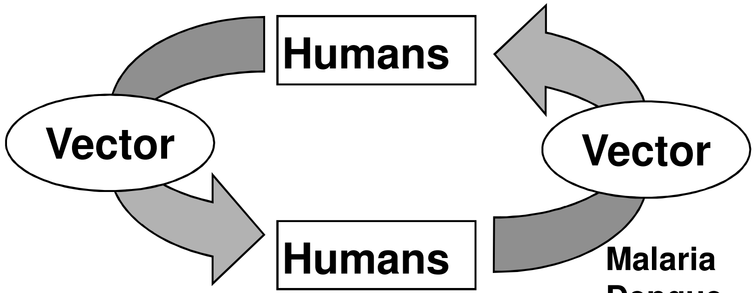
WHO 2009

Vector-borne Disease

- **What is VBD?**
- **Types of VBD transmission:**

Human-vector-human

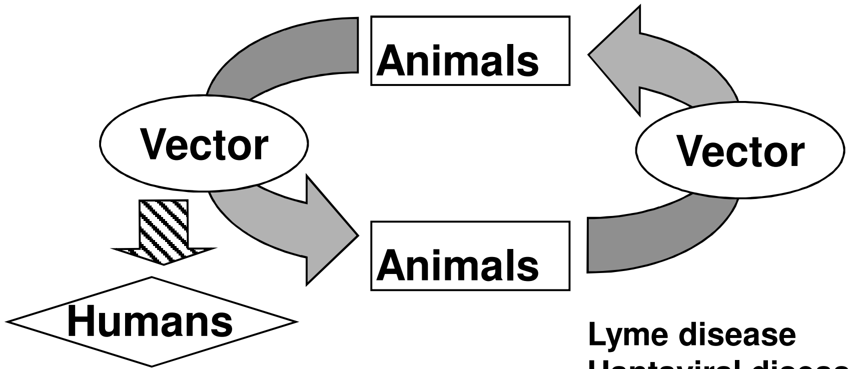
(Anthroponotic Infections)



Malaria
Dengue
Yellow fever

Animal-vector-human

(Zoonotic Infections)



Lyme disease
Hantaviral disease
Most arboviral diseases (e.g., WNV)

WHO 2009

Some Emerging Vector-Borne Diseases

Infection	Distribution	Vector
Barmah Forest virus	Australia	Mosquitoes
Cat flea typhus	United States	Fleas
Cat-scratch disease	Global	Fleas, *Ctenocephalides felis*
Dengue hemorrhagic fever	Americas, Asia	*Aedes* (*Stegomyia*) mosquitoes
Human ehrlichiosis—monocytic	Americas, Asia, Europe	Ticks
Human ehrlichiosis—granulocytic	United States, Europe	Ticks
Kyasanur forest disease	India	Ticks
O'nyong-nyong fever	East Africa	*Anopheles* mosquitoes
Oriental spotted fever	Japan	Ticks?
Oropouche virus	South America, Panama	*Culicoides* midges
Potasi virus	United States	Mosquitoes
Rocio virus	Brazil	Mosquitoes

Gratz 1999

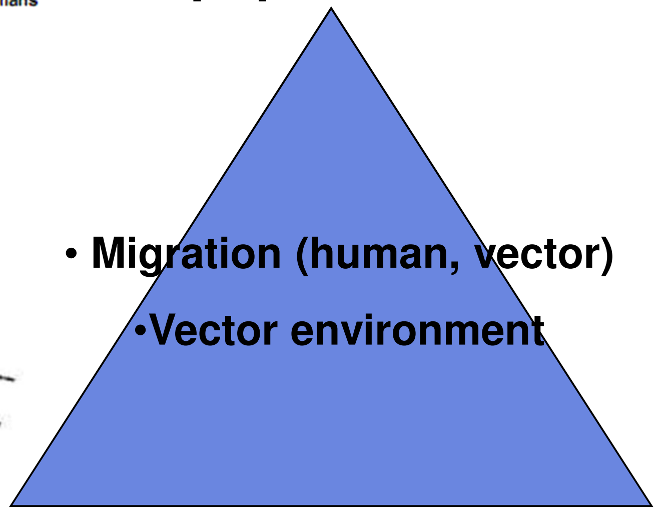
Some Resurging Vector-Borne Diseases

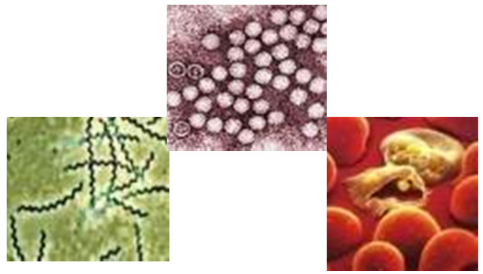
Infection	Distribution	Vectors
Chikungunya	Africa, Asia	*Aedes* (*Stegomyia*) mosquitoes
Congo-Crimean hemorrhagic fever	Africa, Asia, Europe	Ticks
Dengue	Africa, Americas, Asia	*Aedes* (*Stegomyia*) mosquitoes
Filariasis-bancroftian	Africa, Americas, Asia	Mosquitoes
Japanese encephalitis	Asia	*Culex* mosquitoes
Leishmaniasis visceral	Africa, Americas, Asia	Sandflies
Leishmaniasis cutaneous	Global	Sandflies
Lyme disease	Global	Ticks
Malaria	Global	*Anopheles* mosquitoes
Plague	Africa, Americas, Asia	Fleas
Rift Valley fever	Africa	Mosquitoes
Ross River virus	Australia, Pacific islands	Mosquitoes
Trench fever	United States, Europe	Body lice
Venezuelan equine encephalitis	Americas	Mosquitoes
Yellow fever	Africa, Americas	*Aedes* (*Stegomyia*) mosquitoes

Gratz 1999

Vector-borne Disease Dynamics

Susceptible population





Vector

- Survival, lifespan
- Reproduction/breeding patterns
- Biting behavior

Pathogen

- Survival
- Transmission
- Replication in host

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Climate vs. Weather Effects

Climate

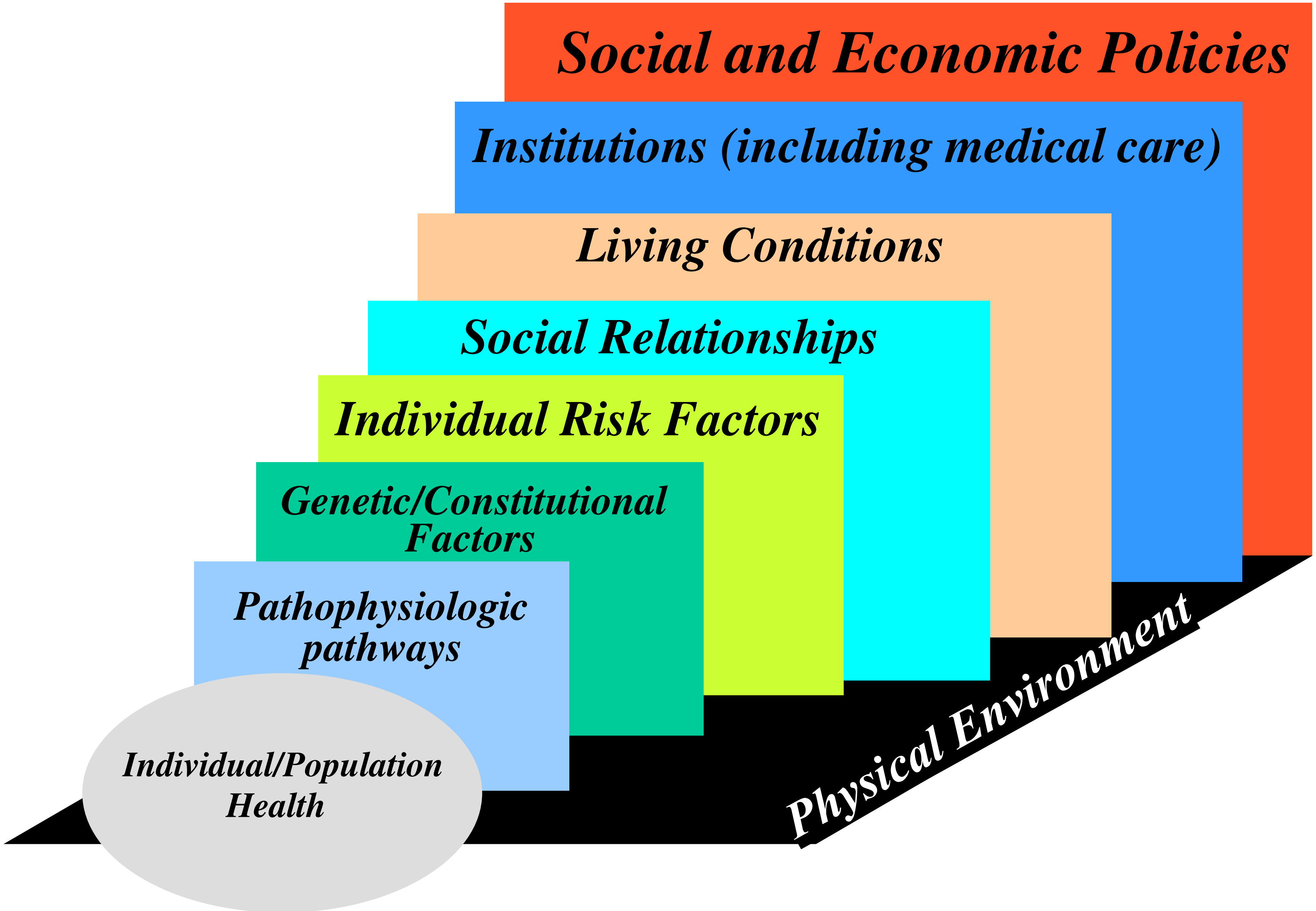
- Average trend of weather patterns for a given location (averages over a long time period)
- Constrains the range of infectious disease
- E.g., malaria possibly in Kenyan Highlands

Weather

- Day-to-day climate conditions for a given location (shorter time periods, highly variable)
- Affects the timing and intensity of outbreaks
- E.g., dengue outbreaks in Sumatra

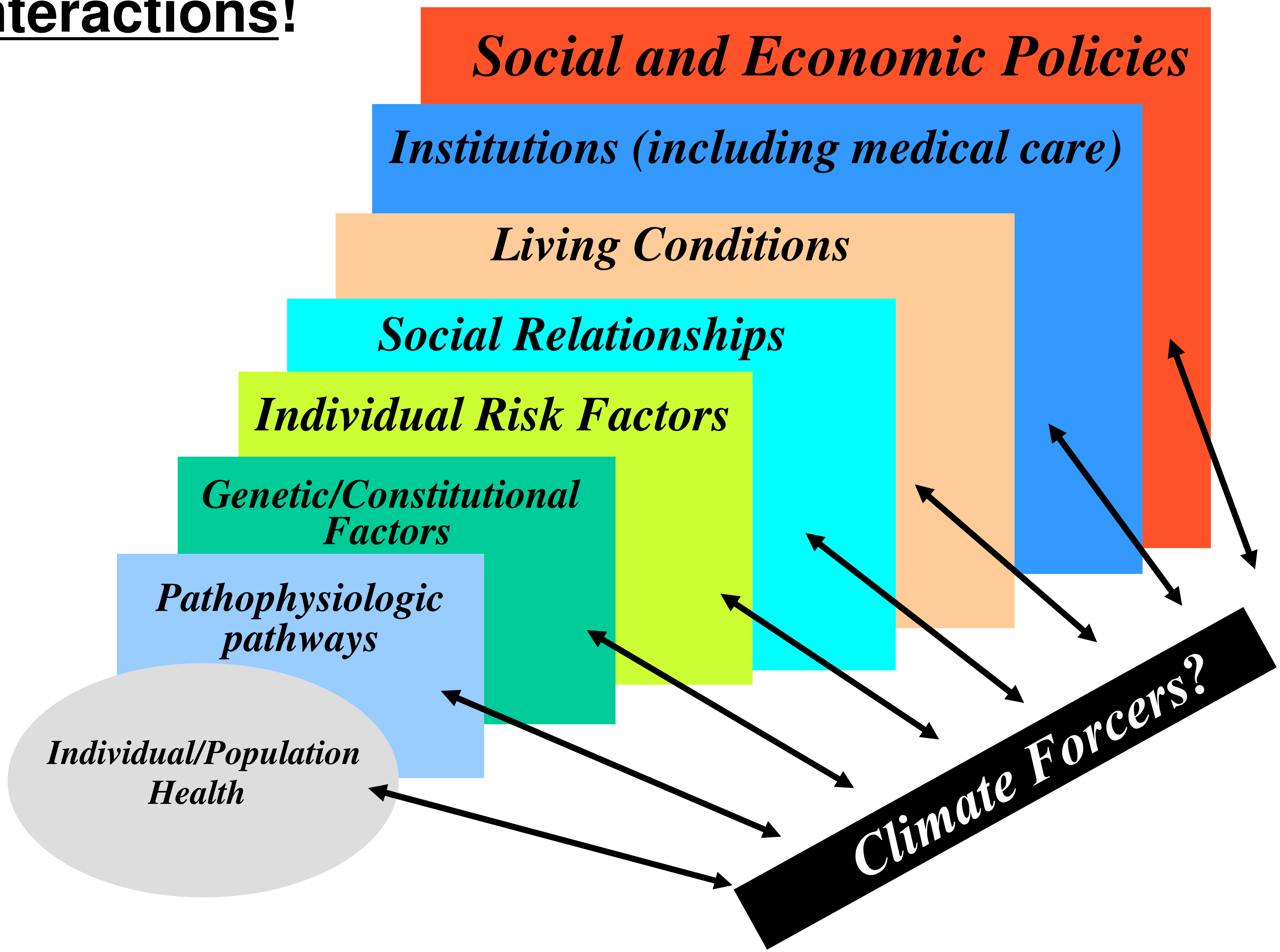
Epstein, 2001; Patz, 2002

Environmental Determinants of Human Disease



Modified from Kaplan, 2002

Research Challenge – Analyze and Understand Interactions!



Direct Effects of Climate Change on Vector-borne Disease

- **Climate change has the potential to**
  - **Increase range or abundance of animal reservoirs and/or arthropod vectors**
    - **(e.g., Lyme, Malaria, Schistosomiasis)**
  - **Enhance transmission**
    - **(e.g., West Nile virus and other arboviruses)**
  - **Increase importation of vectors or pathogens**
    - **(e.g., Dengue, Chikungunya, West Nile virus)**
  - **Increase animal disease risk and potential human risk**
    - **(e.g., African trypanosomiasis)**

Greer et al., 2008

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Temperature Effects on Vectors and Pathogens

- **Vector**
  - Survival decrease/increase depending on the species
  - Changes in the susceptibility of vectors to some pathogens
  - Changes in rate of vector population growth
  - Changes in feeding rate and host contact
- **Pathogen**
  - Decreased extrinsic incubation period of pathogen in vector at higher temperatures
  - Changes in the transmission season
  - Changes in geographical distribution
  - Decreased viral replication

Gubler et al., 2001

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Precipitation Effects on Vectors

- **Vector**
  - Survival: increased rain may increase larval habitat
  - Excess rain can eliminate habitat by flooding
  - Low rainfall can create habitat as rivers dry into pools (dry season malaria)
  - Decreased rain can increase container-breeding mosquitoes by forcing increased water storage
  - Heavy rainfall events can synchronize vector host-seeking and virus transmission
  - Increased humidity increases vector survival and vice-versa

Gubler et al., 2001

Precipitation Effects on Pathogens

- **Pathogen**
  - **Few direct effects but some data on humidity effects on malarial parasite development**

Gubler et al., 2001

Vector Activity

- **Increased relative humidity increases activity, heavy rainfall decreases activity**
- **Increased activity increases transmission rates**

National Geographic

Ranger DJ

Ogden et al., 2005;
Vail and Smith, 1998

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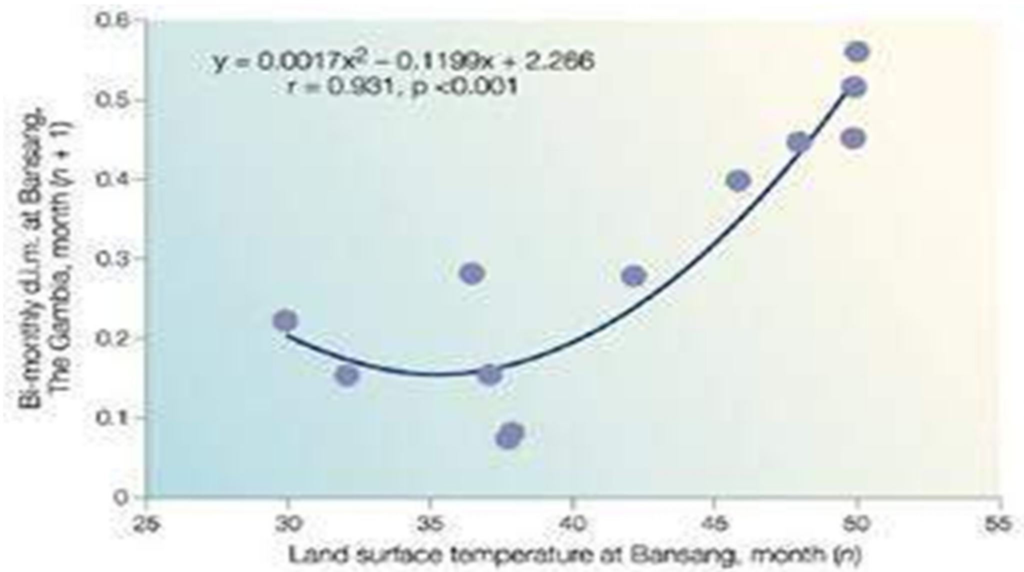
Vector Survival

- **Direct effects of temperature on mortality rates***
- **Temperature effects on development: at low temperatures, lifecycle lengthens and mortality outstrips fecundity***

* **Non-linear (quadratic) relationships with temperature**



Tsetse mortality,
Rogers and Randolph, 2003

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Vector and Host <u>Seasonality</u>

- Vector-borne zoonoses mostly maintained by wildlife
  - Humans are irrelevant to their ecology
- Vectors and their hosts are subject to seasonal variations that are climate related (e.g., temperature) and climate independent (e.g., day-length)
- Seasonal variations affect abundance and demographic processes of both vectors and hosts

Vector and Host Seasonality (cont.)

- Vector seasonality due to temperature affects development and activity → transmission
- Host demographic processes (reproduction, birth and mortality rates), affected directly by weather and indirectly by resource availability → VBD epidemiology

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Evidence Reviewed by the IPCC

- **Emerging evidence shows:**
  - **Altered the distribution of some infectious disease vectors** ***(medium confidence)***
  - **Altered the seasonal distribution of some allergenic pollen species** ***(high confidence)***
  - **Increased heatwave-related deaths** ***(medium confidence)***

IPCC AR4, 2007

Evidence of Climate Change Effects

- **Some specific disease examples:**
  - **Malaria — East African highlands**
  - **Lyme disease — Canada**
  - **Schistosomiasis — China**
  - **Bluetongue Europe**

Source: CDC

Source: USDA

Source: Davies Laboratory

Source: DEFRA

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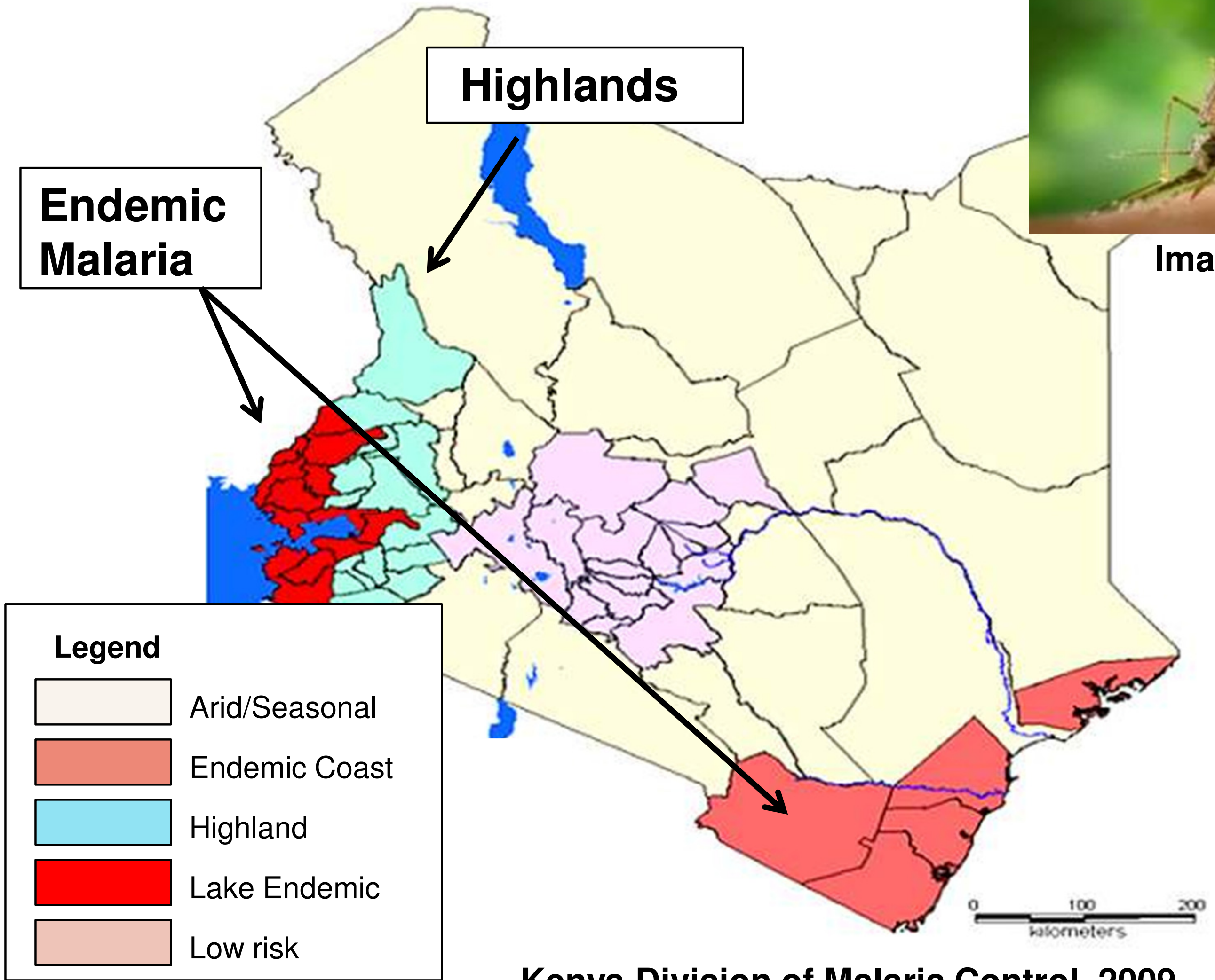
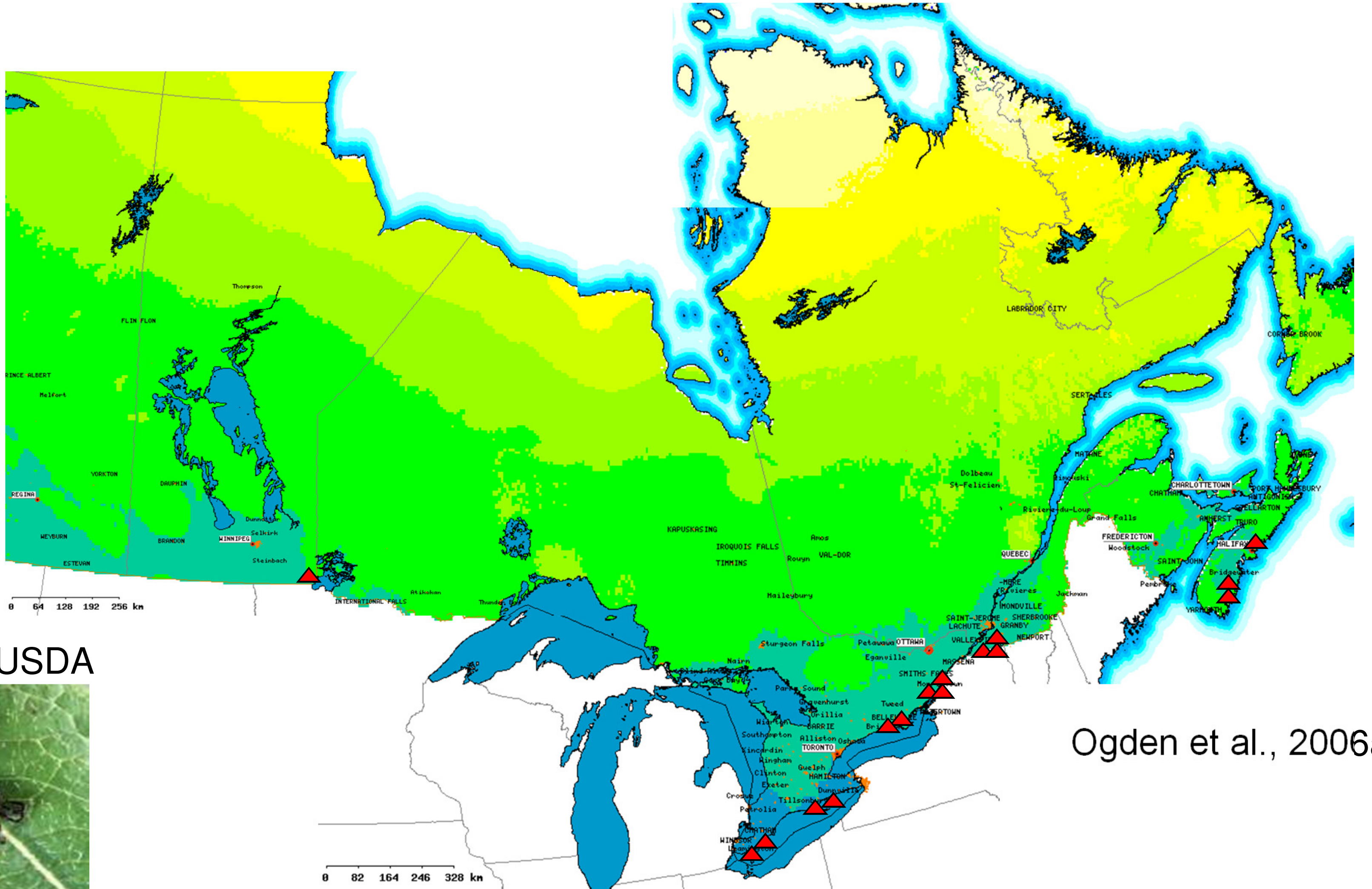
Evidence: Malaria in Kenya



Kenya Division of Malaria Control, 2009

Image source: CDC

Evidence: Lyme Disease



Ogden et al., 2006a

Source: USDA

1970 → 1997 → 2007

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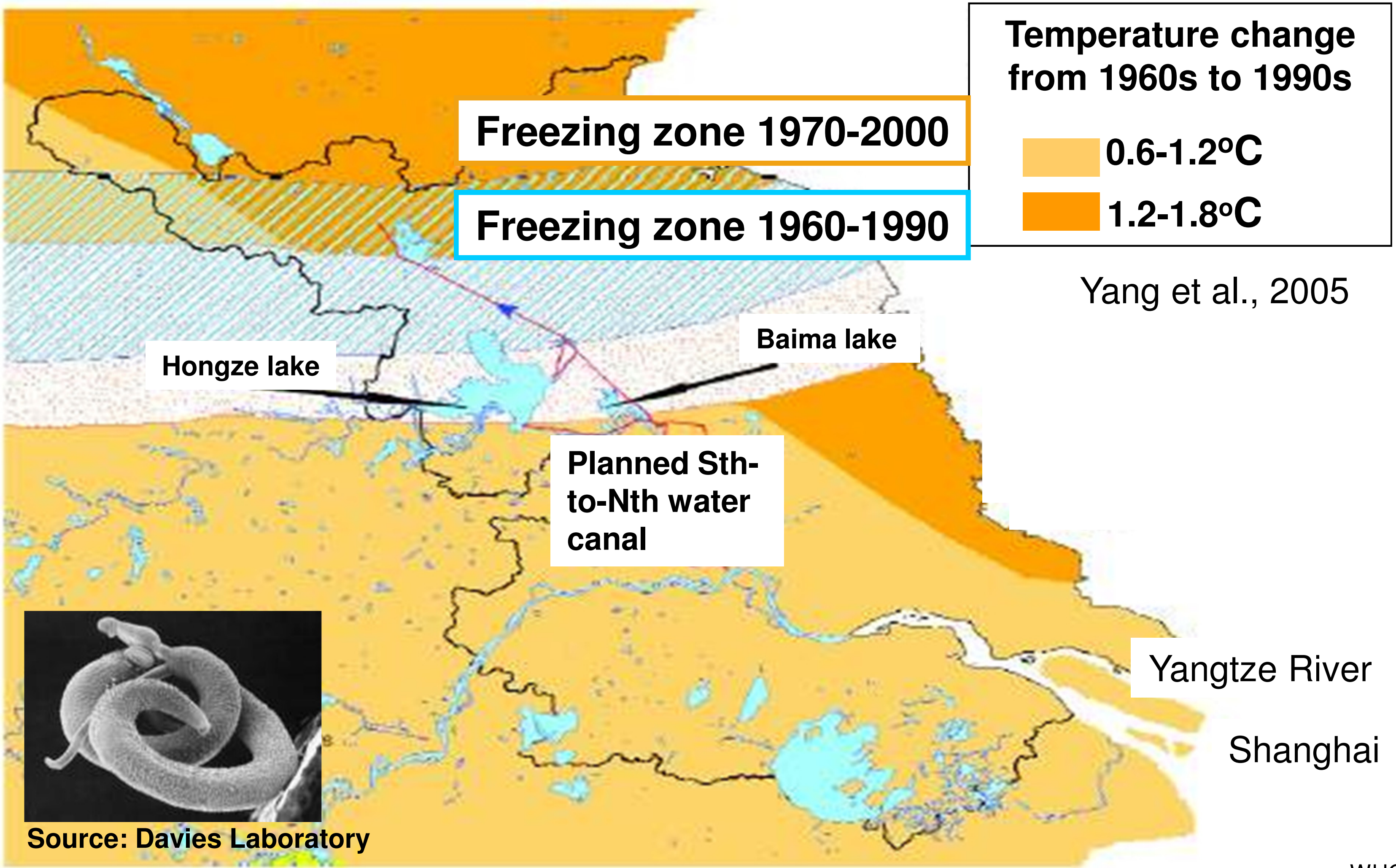
Evidence: Schistosomiasis



Yang et al., 2005

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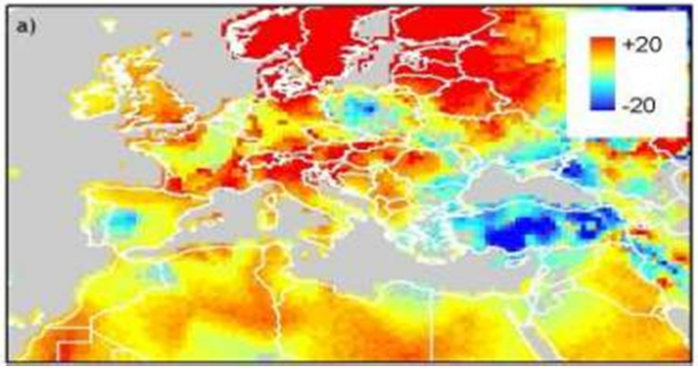
Evidence: Bluetongue Disease

- *Culicoides* midge range previously restricted by Spain (south), Portugal (west), Greek islands (east)
- Now spread across southern Europe including France and Italy and moving northward
- Spatial congruence between Bluetongue incidence and climate changes support link

Purse et al., 2005

Temperature change: 1980s vs. 1990s



Culicoides biting midge

Source: DEFRA

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Summary of Climate Change Effects

- **Climate change has the potential to**
  - **Increase range or abundance of animal reservoirs and/or arthropod vectors**
    - **Lyme, Malaria, Schistosomiasis**
  - **Prolong transmission cycle**
    - **Malaria, West Nile virus, and other arboviruses**
  - **Increase importation of vectors or animal reservoirs**
    - **Dengue, Chikungunya, West Nile virus**
  - **Increase animal disease risk and potential human risk**
    - **African trypanosomiasis**

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Emerging\Re-emerging Infectious Diseases

- **Introduction of exotic parasites into existing suitable host/vector/human-contact ecosystem (West Nile)**
- **Geographic spread from neighboring endemic areas (Lyme)**
- **Ecological change causing endemic disease of wildlife to "spill-over" into humans/domesticated animals (Lyme, Hantavirus, Nipah)**
- **True "emergence": evolution and fixation of new, pathogenic genetic variants of previously benign parasites/pathogens (HPAI)**

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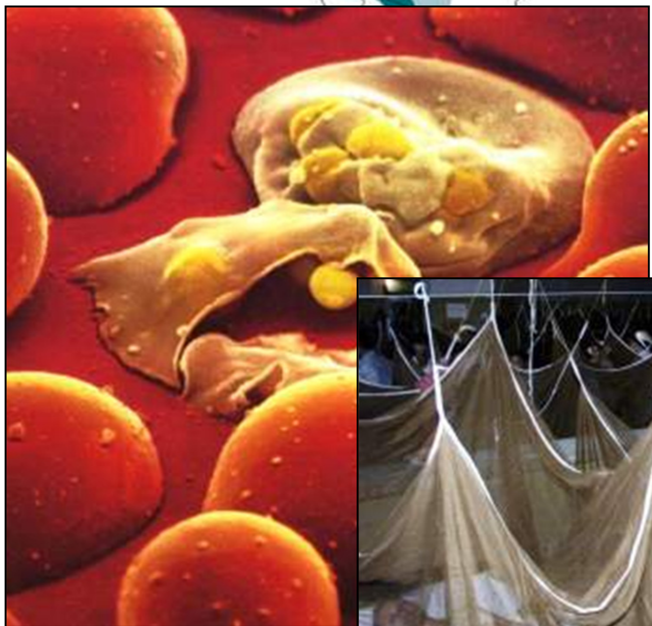
Case Study I: Malaria



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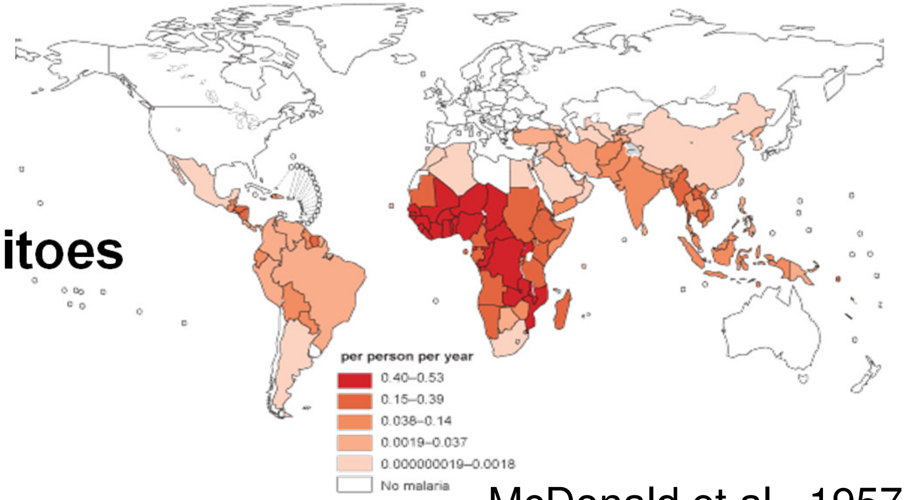
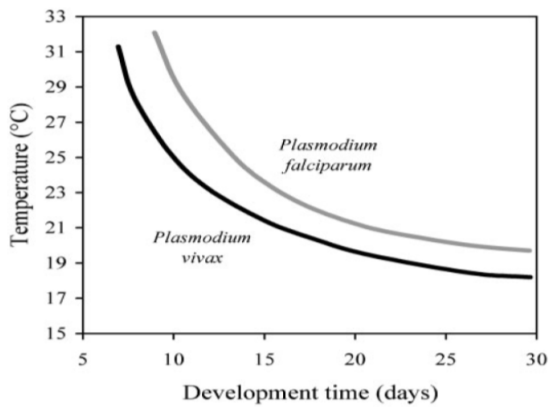
Case Study I: Malaria (cont.)

- **40% world population at risk**
- **500 million severely ill**
- **Climate sensitive disease[1]**
  - **No transmission where mosquitoes cannot survive**
  - ***Anopheles*: optimal adult development 28-32ºC**
  - ***P falciparum* transmission: 16-33ºC**
- **Highland malaria[2]**
  - **Areas on the edges of endemic regions**
- **Global warming → El Niño[3]**
  - **Outbreaks**

Estimated incidence of clinical malaria episodes (WHO)



McDonald et al., 1957



[1] Khasnis and Nettleman 2005; [2] Patz and Olson 2006; [3] Haines and Patz, 2004

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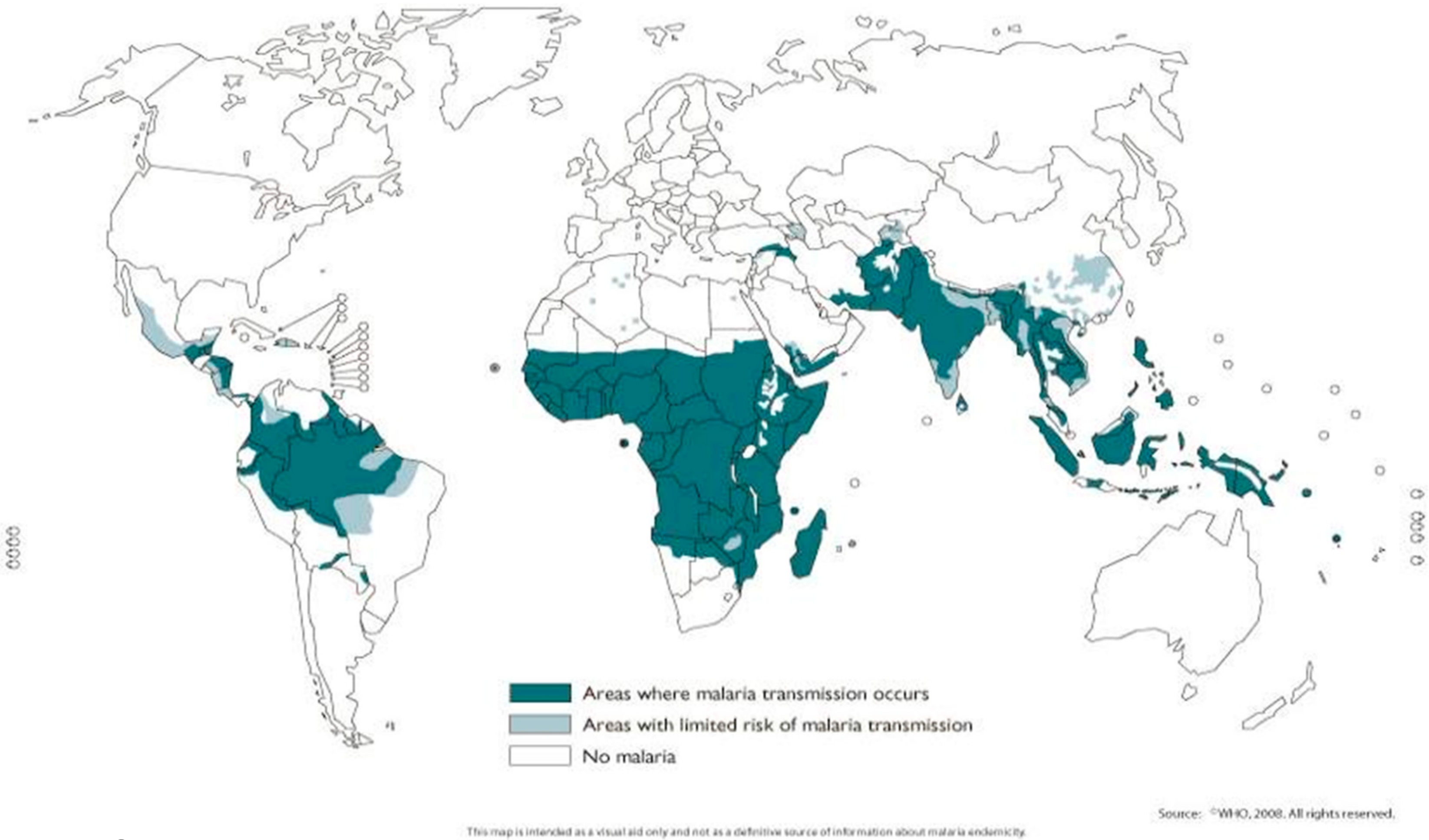
Malaria Transmission Map



WHO, 2008b

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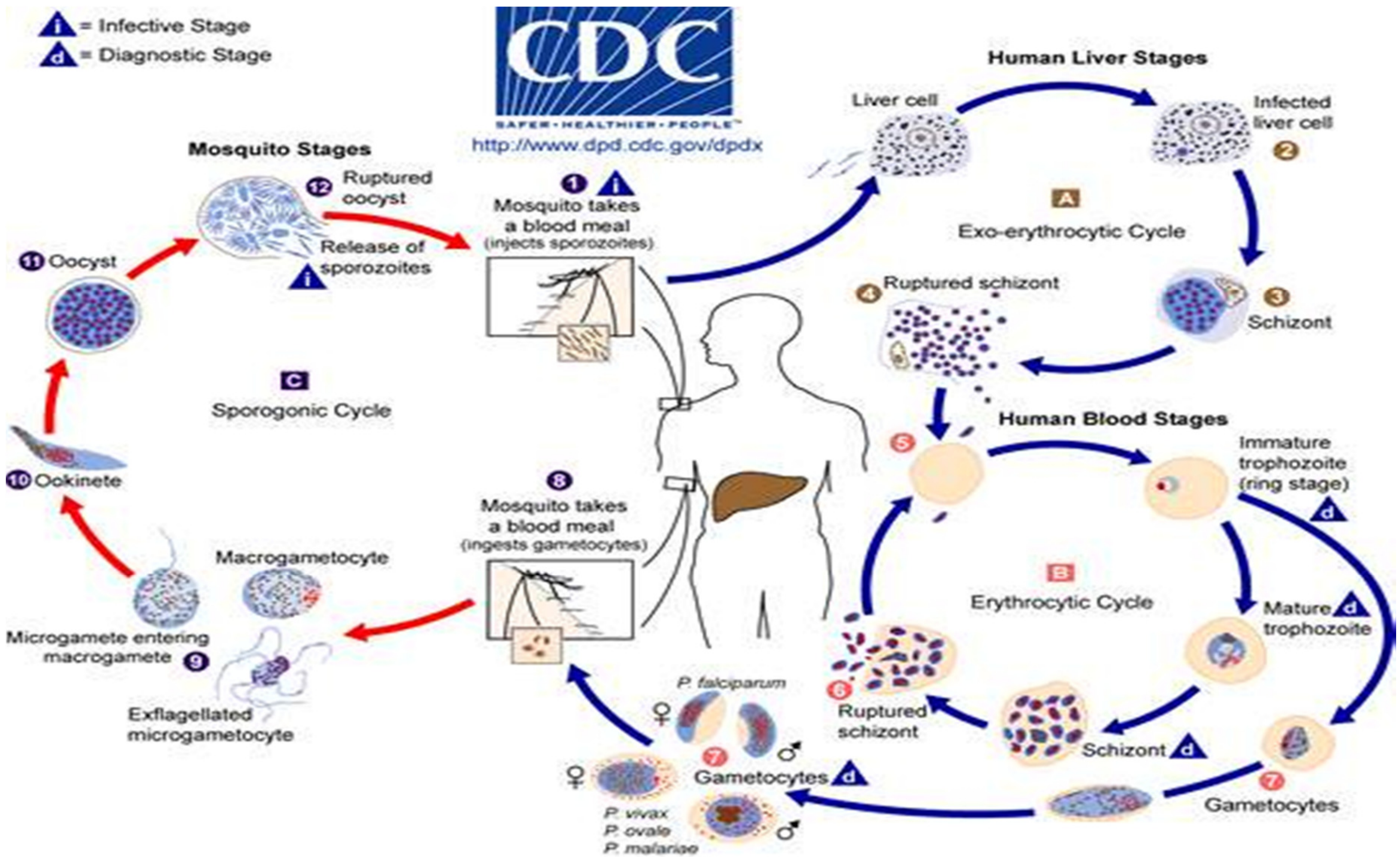
Transmission Cycles of Malaria



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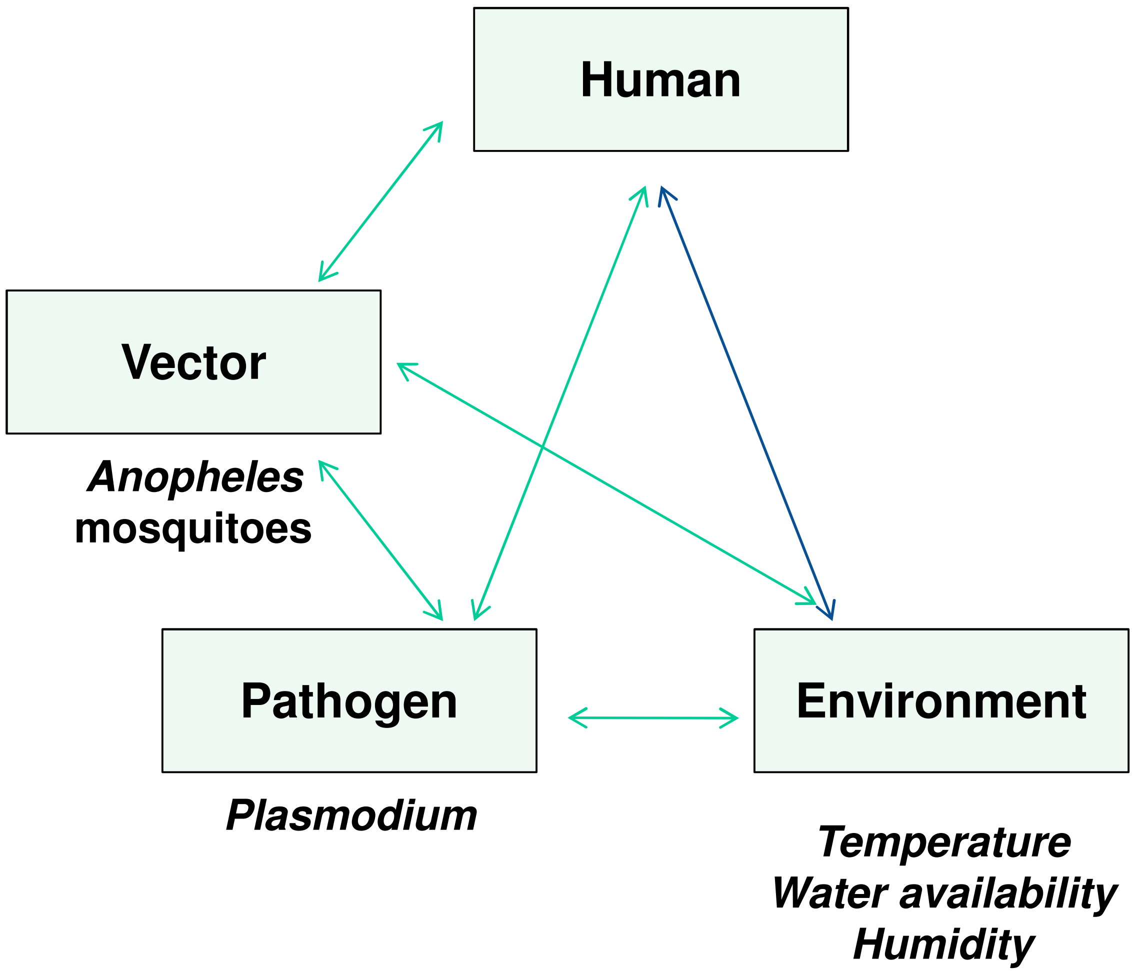
Climate Impacts on Malaria

What are some of the potential direct and indirect pathways of influence?



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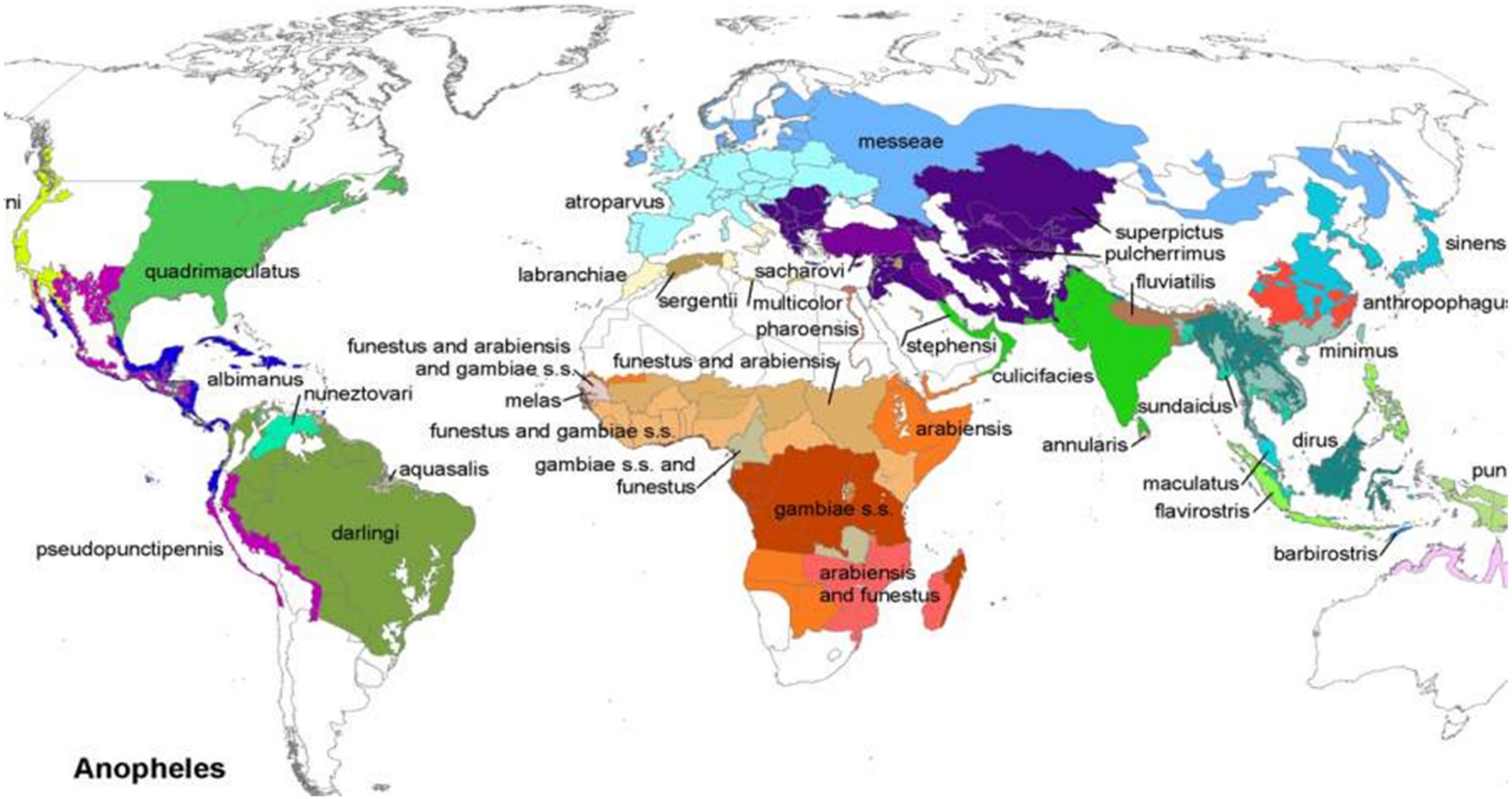
Competent Vectors



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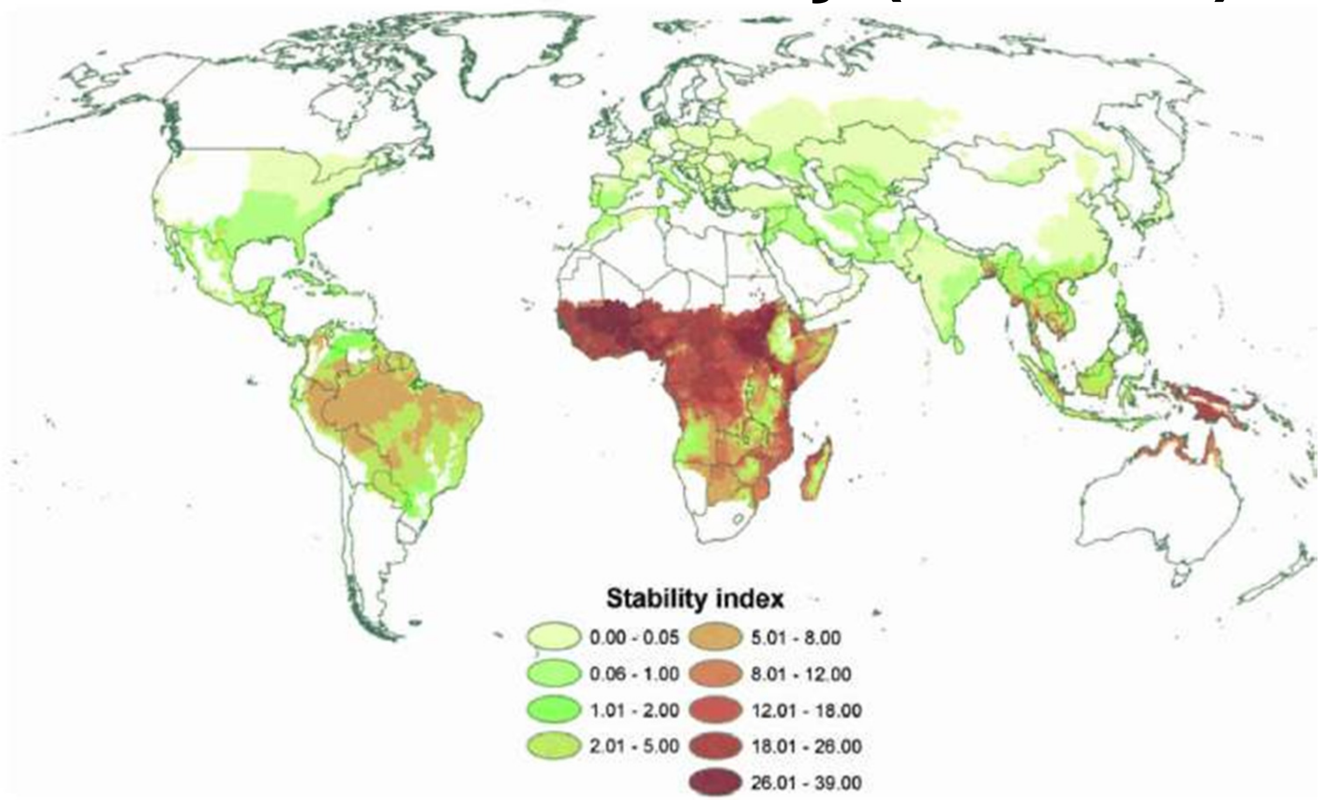
Malaria Endemicity (Current)



"Climate change related exposures... will have mixed effects on malaria; in some places the geographical range will contract, elsewhere the geographical range will expand and the transmission season may change (*very high confidence*)." (IPCC 2007)

WHO 2009

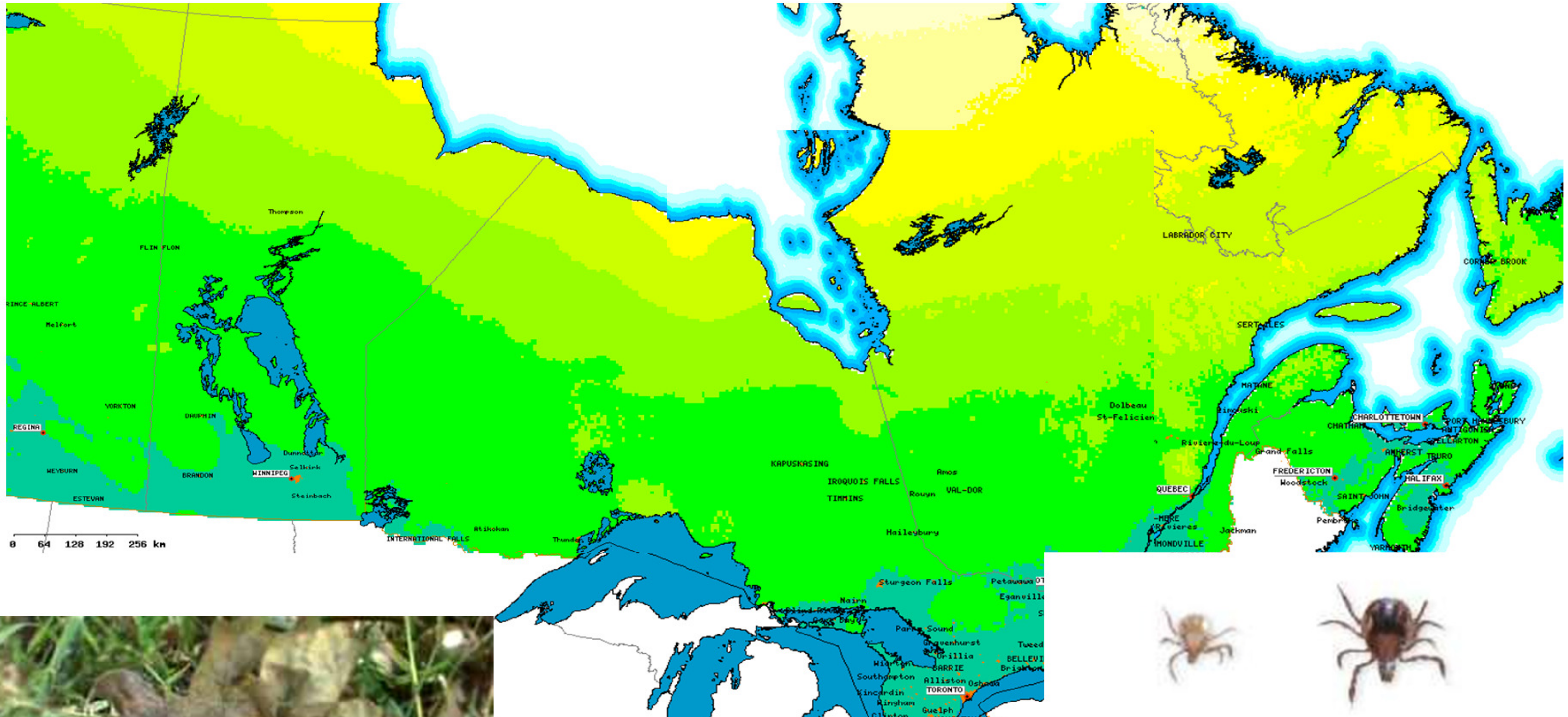
Projections for Malaria

WHO 2009

Recent Example: Improving Malarial Occurrence Forecasting in Botswana

- From annual time-series data: statistical relationship between summer (Dec-Jan) rainfall and post-summer annual malaria incidence (Thomson et al., 2006)
- Model applied, with good success, to previous meteorologically-modeled forecasts of summer rainfall
- This extended (by several months) the early-warning of post-summer malaria risk

Case Study 2: Lyme Disease



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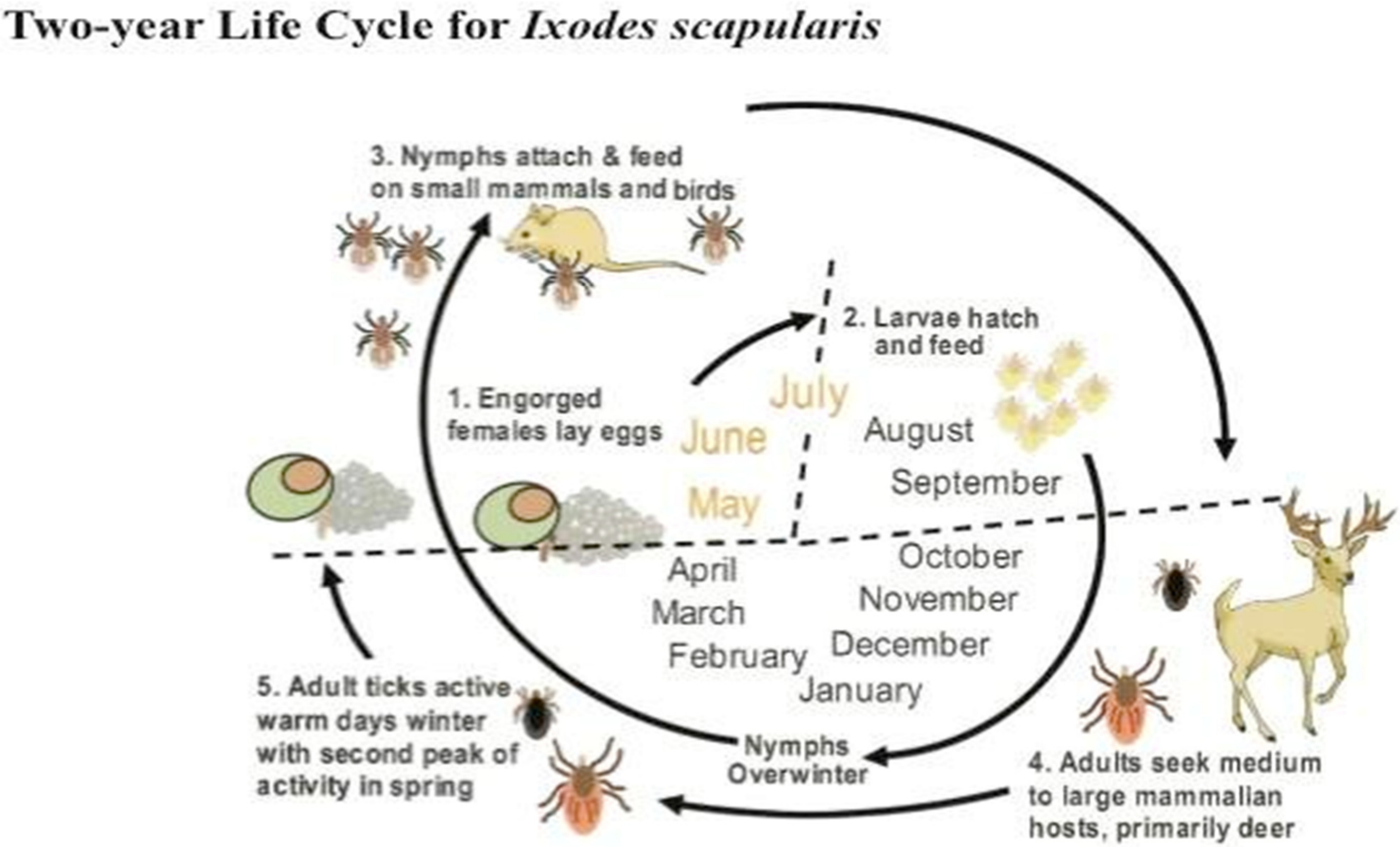
Transmission Cycle of Lyme Disease

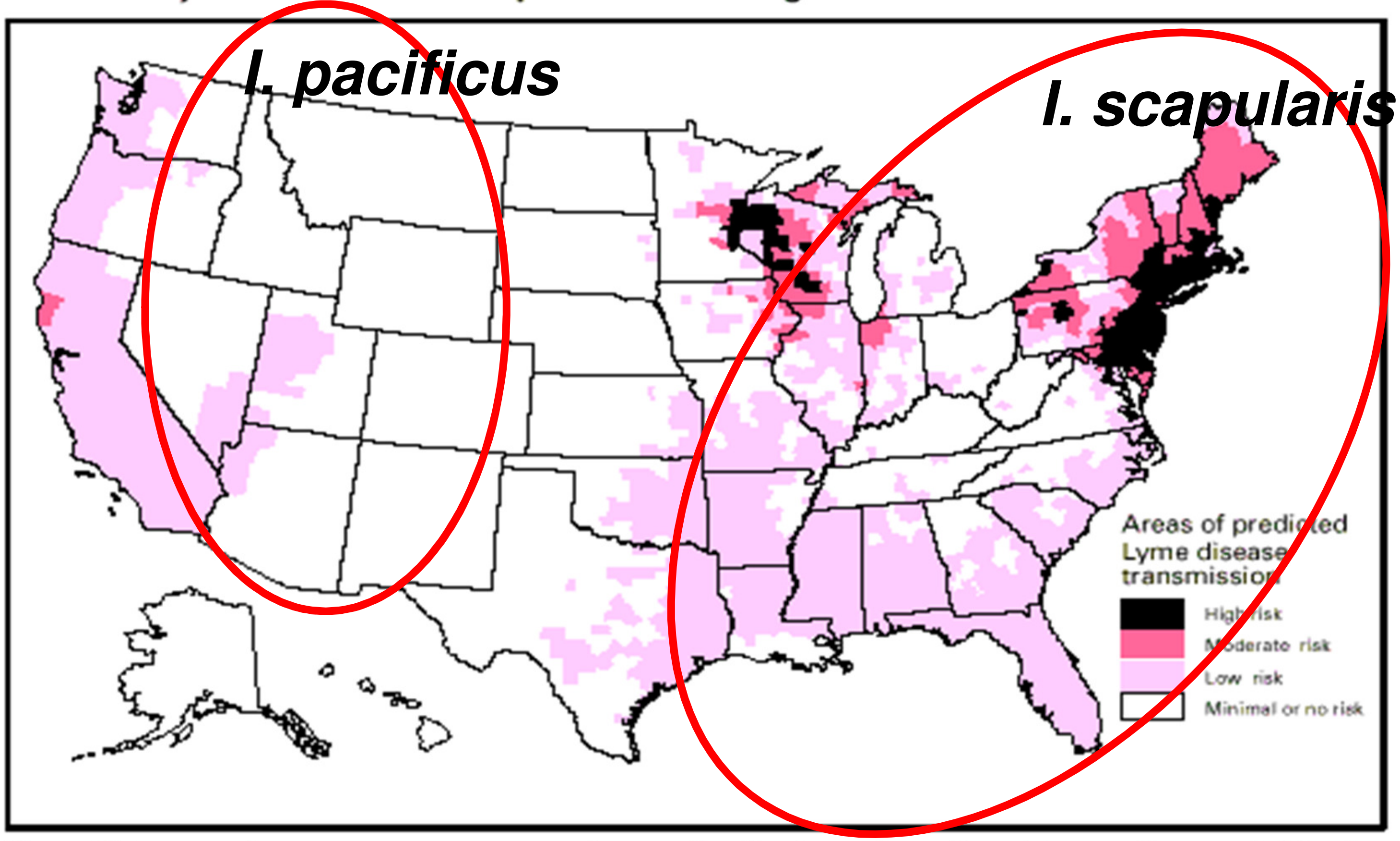


Stafford, 2007

WHO 2009

Lyme Disease Distribution in the Unites States of America

National Lyme disease risk map with four categories of risk



Note: This map demonstrates an approximate distribution of predicted Lyme disease risk in the United States. The true relative risk in any given county compared with other counties might differ from that shown here and might change from year to year. Risk categories are defined in the accompanying text. Information on risk distribution within states and counties is best obtained from state and local public health authorities.

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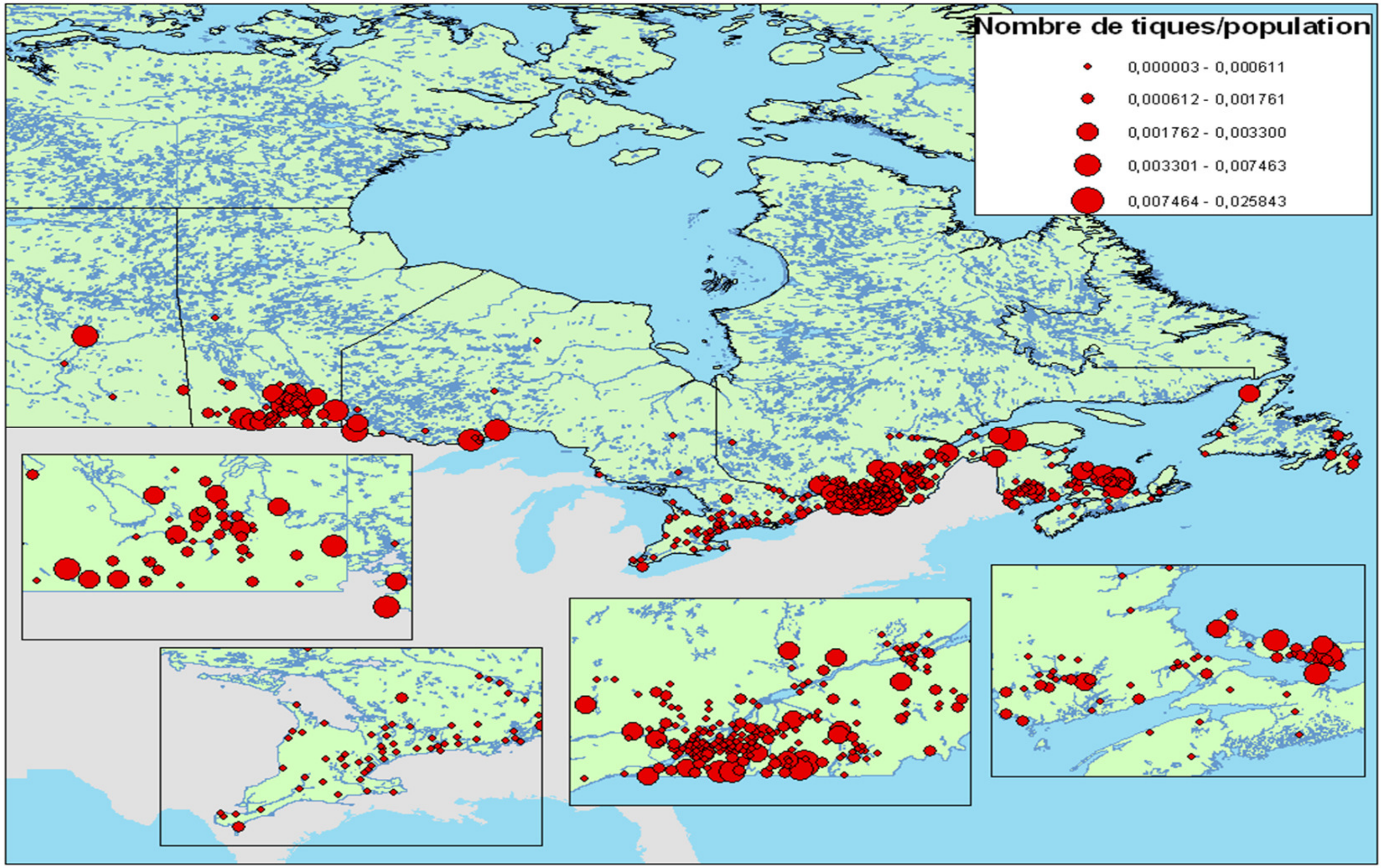
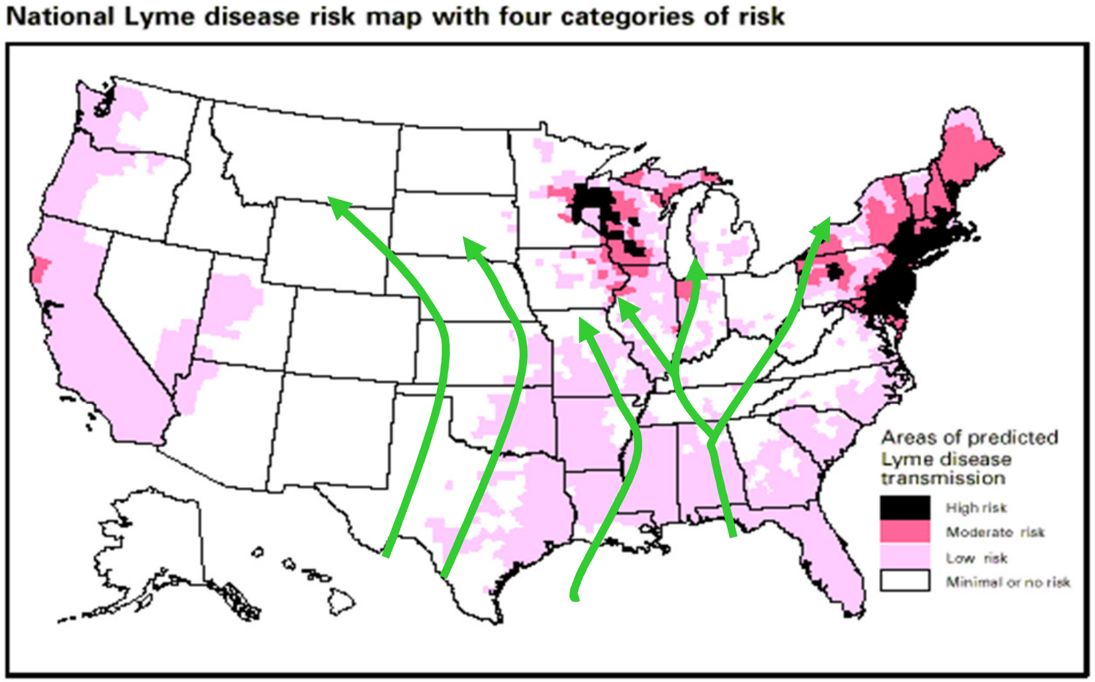
Passive Surveillance: Migratory Bird Distribution of Ticks (*I. Scapularis*)



Ogden et al., 2006a, 2008

Hypothesis: Migratory Birds Carry *I. scapularis* Into, and Through, Canada



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Northern-migrating ground-feeding birds stop-over in tick-infested habitat

Spring migration coincides with spring activity period of *Ixodes scapularis* nymphs

Nymphs feed continuously on birds for 4-5 days, then drop off into the habitat

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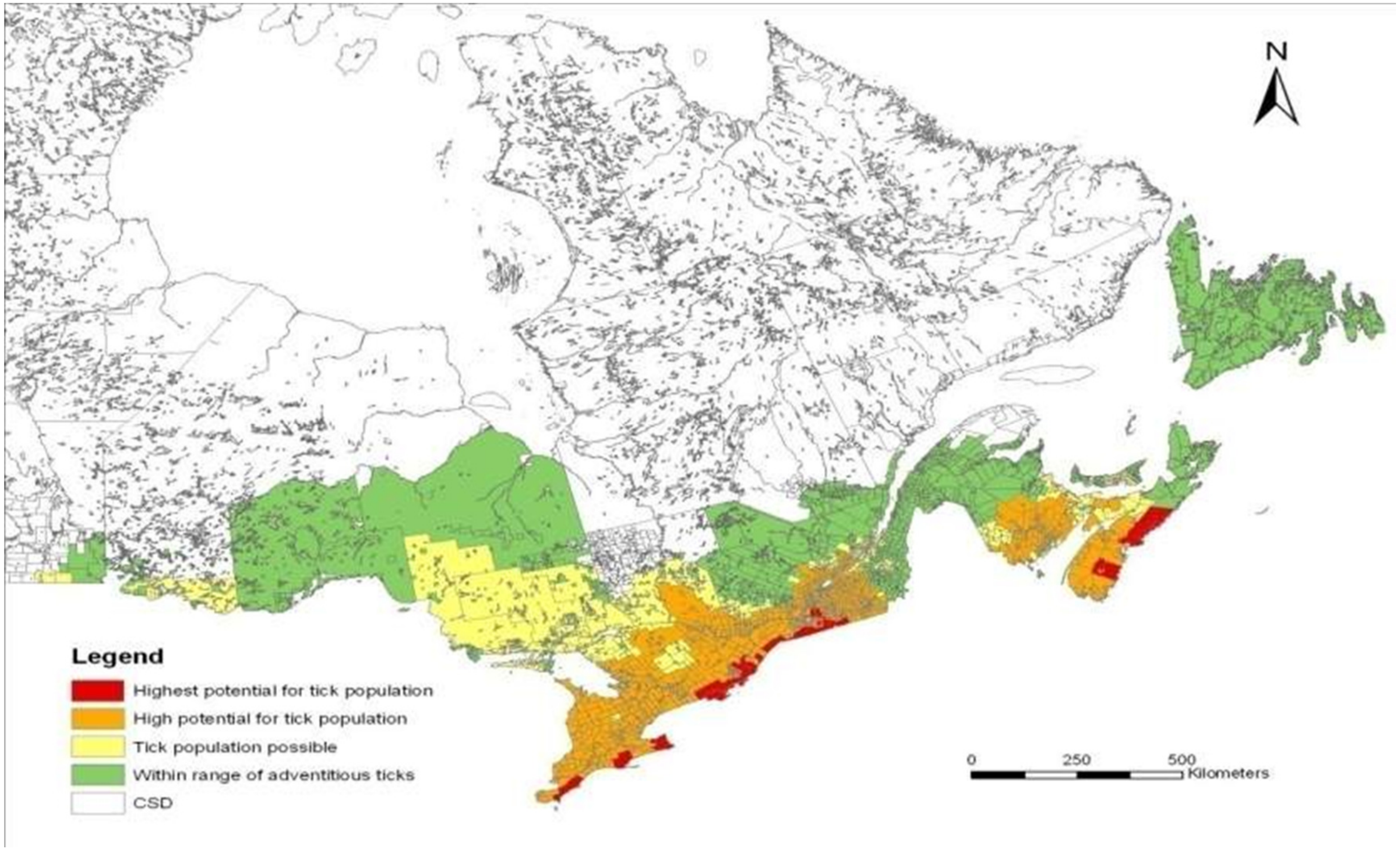
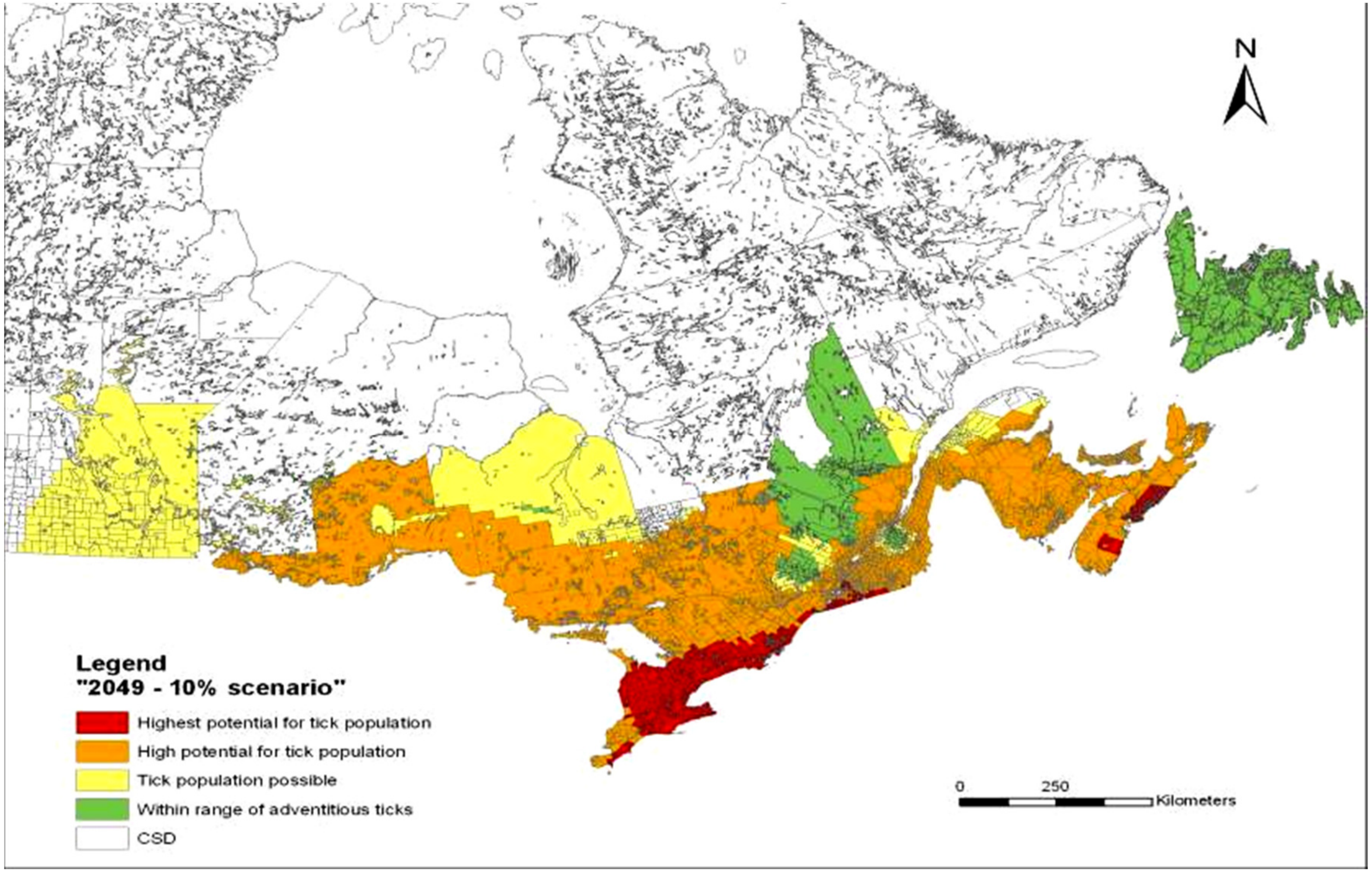
Prediction of Potential Extent of *I. scapularis* Populations at Present



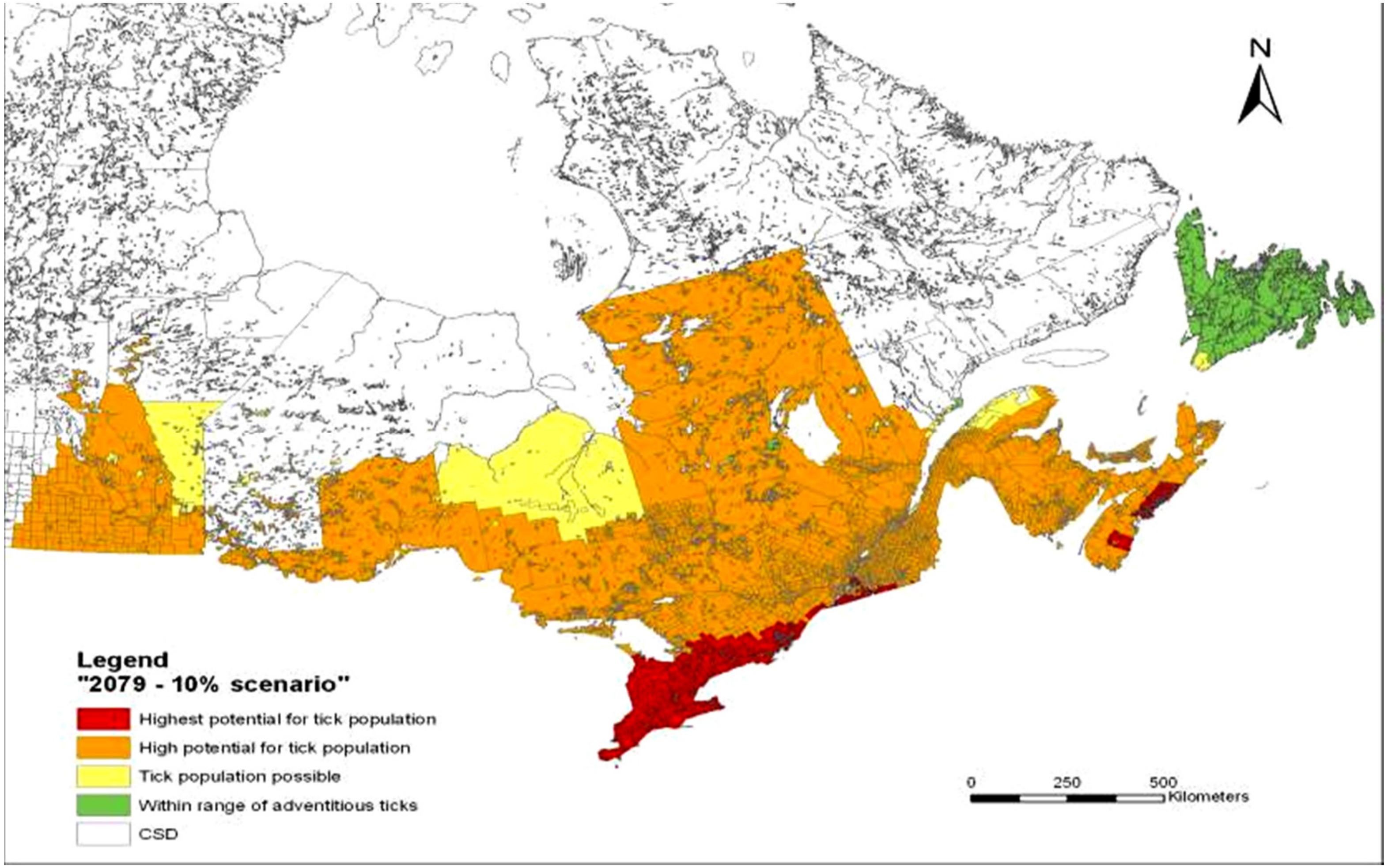
Ogden et al., 2008

Prediction of Potential Extent of *I. scapularis* Populations by 2049



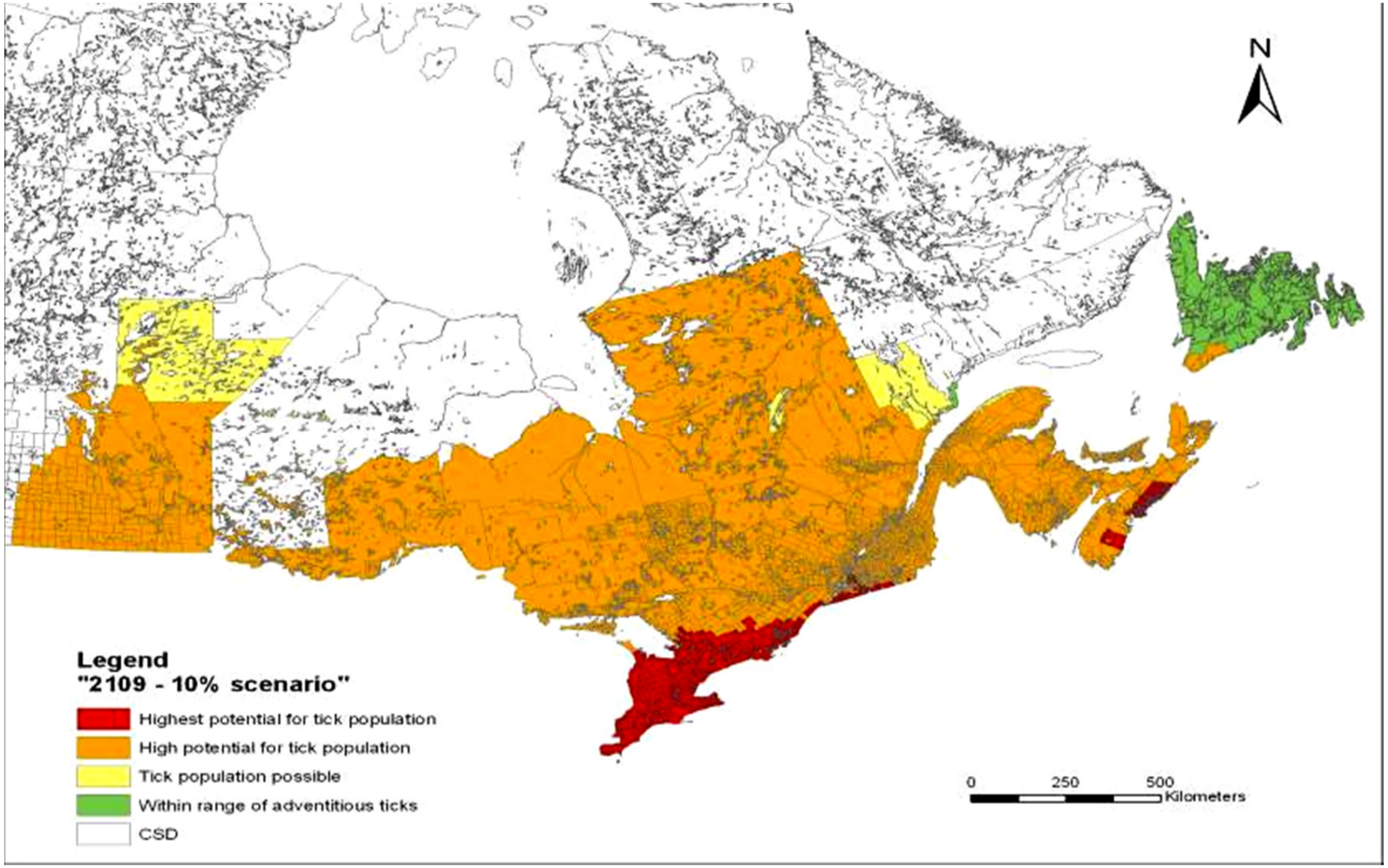
Ogden et al., 2008

Prediction of Potential Extent of *I. scapularis* Populations by 2079



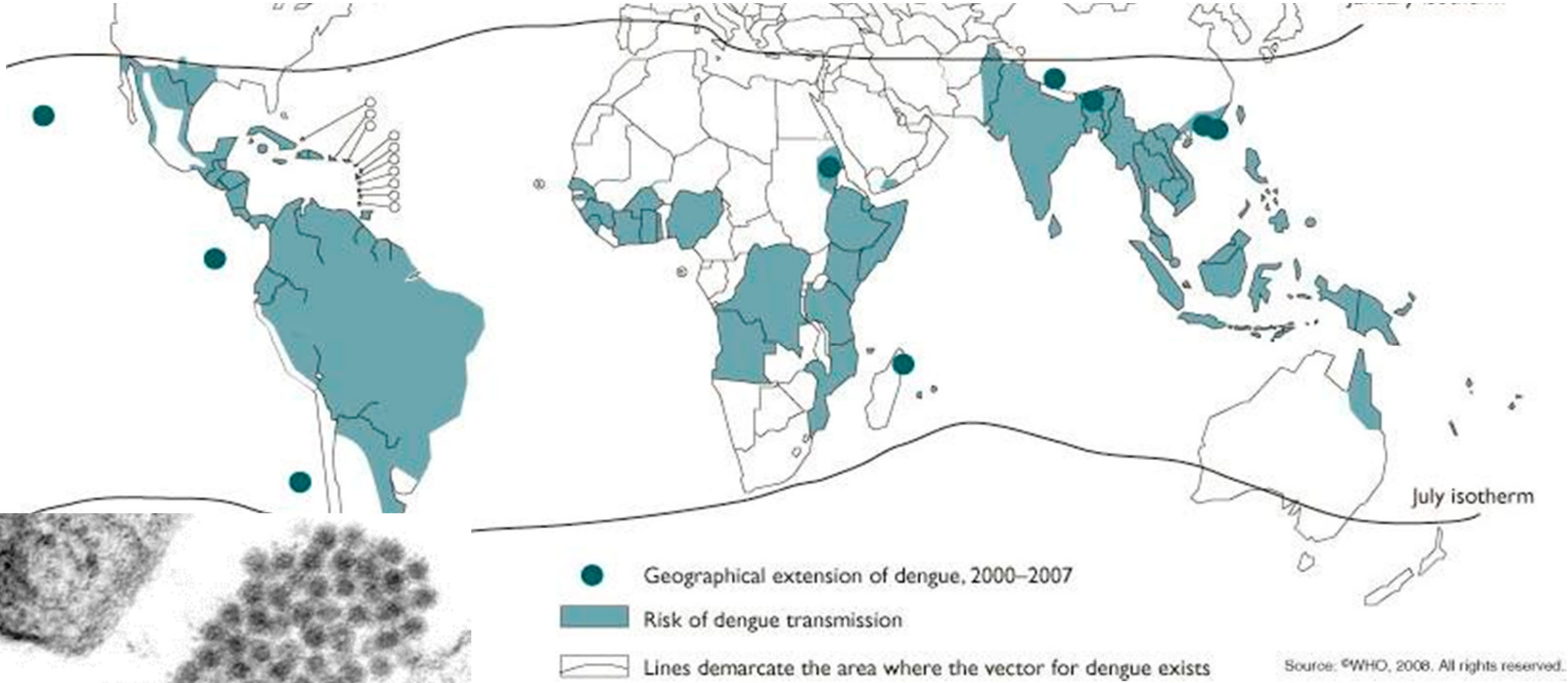
Ogden et al., 2008

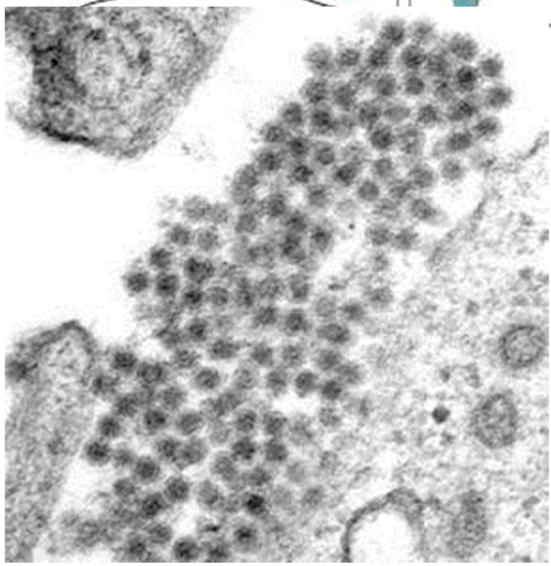
Prediction of Potential Extent of *I. scapularis* Populations by 2109



Ogden et al., 2008

Case Study 3: Dengue





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Climate Variability and Dengue Incidence

Aedes mosquito breeding[1]:

- **Highest abundance mean temp. 20ºC, ↑ accumulated rainfall (150 mm)**
- **Decline egg laying monthly mean temperature <16,5ºC**
- **No eggs temp. <14,8ºC**

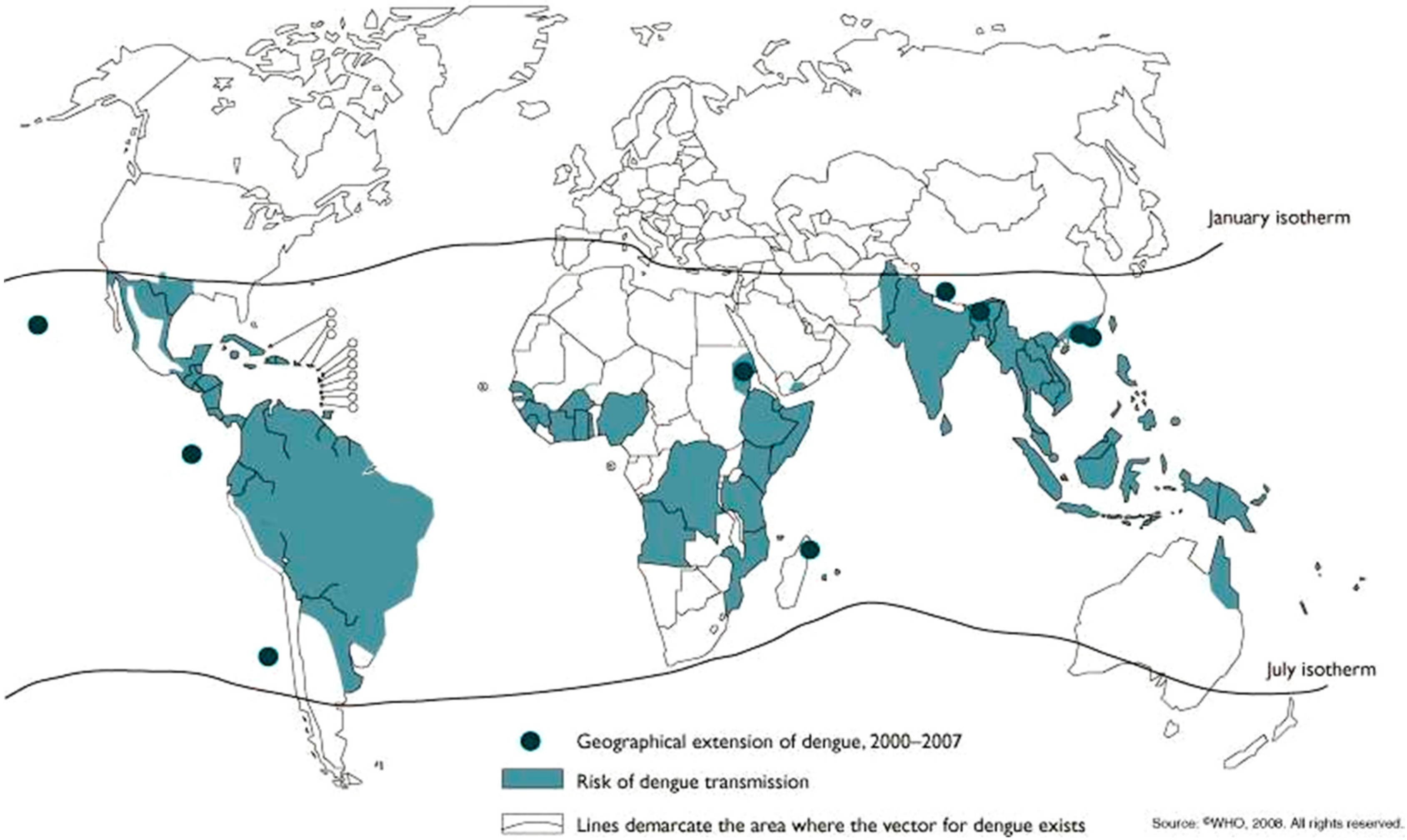
Other studies:

- **Virus replication increases ↑ temperature[2]**
- **Transmission of pathogen ≠ >12ºC[3]**
- **Biological models: small ↑ temperature in temperate regions → increases potential epidemics[4]**

[1]Vezzani et al., 2004; [2]Watts et al., 1987; [3]Patz et al., 2006; [4]Patz et al., 1998

WHO 2009

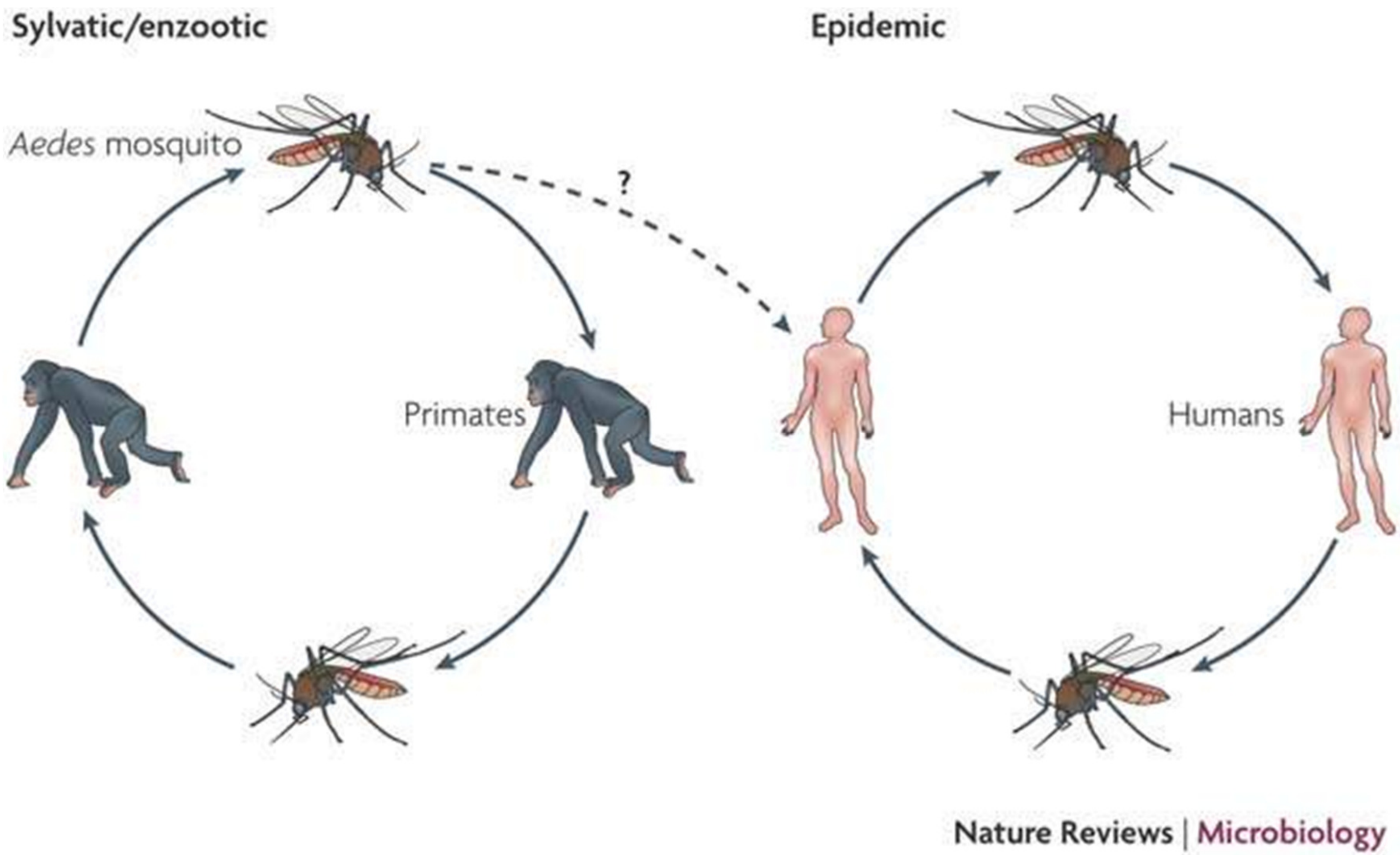
Dengue Transmission Map



WHO, 2008b

WHO 2009

Transmission Cycle of Dengue



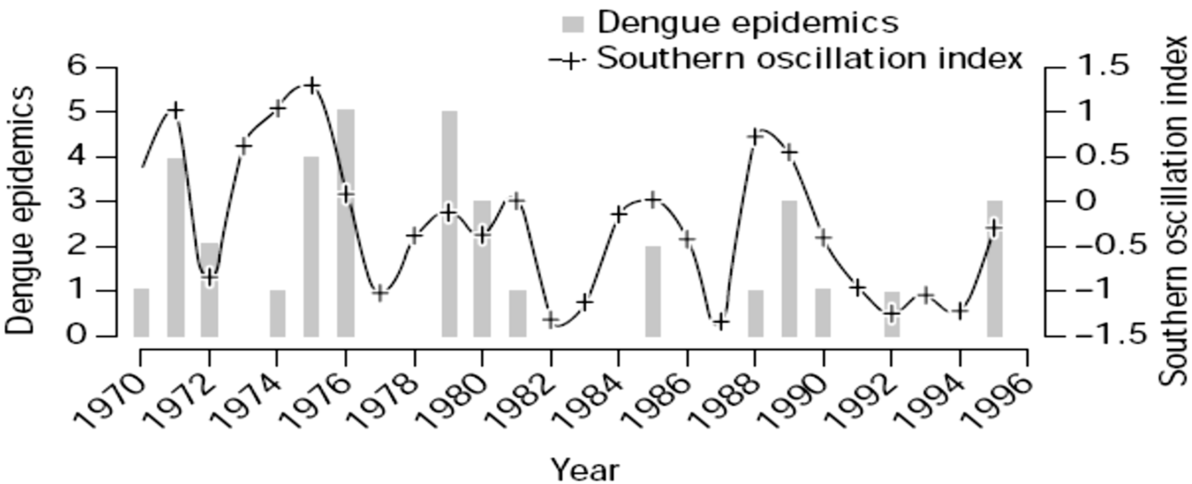
Whitehead et al., 2007

WHO 2009

Example of Weather Effects: El Niño

- **Global warming intensifies El Niño**
- **Several studies found relationships between dengue epidemics and ENSO (El Niño Southern Oscillation)**
- **Drought conditions: increase water storage around houses → elevated *Aedes aegypti* populations**
- **Enhanced breeding opportunities when rainfall accumulates following drought (Kuno et al., 1995)**

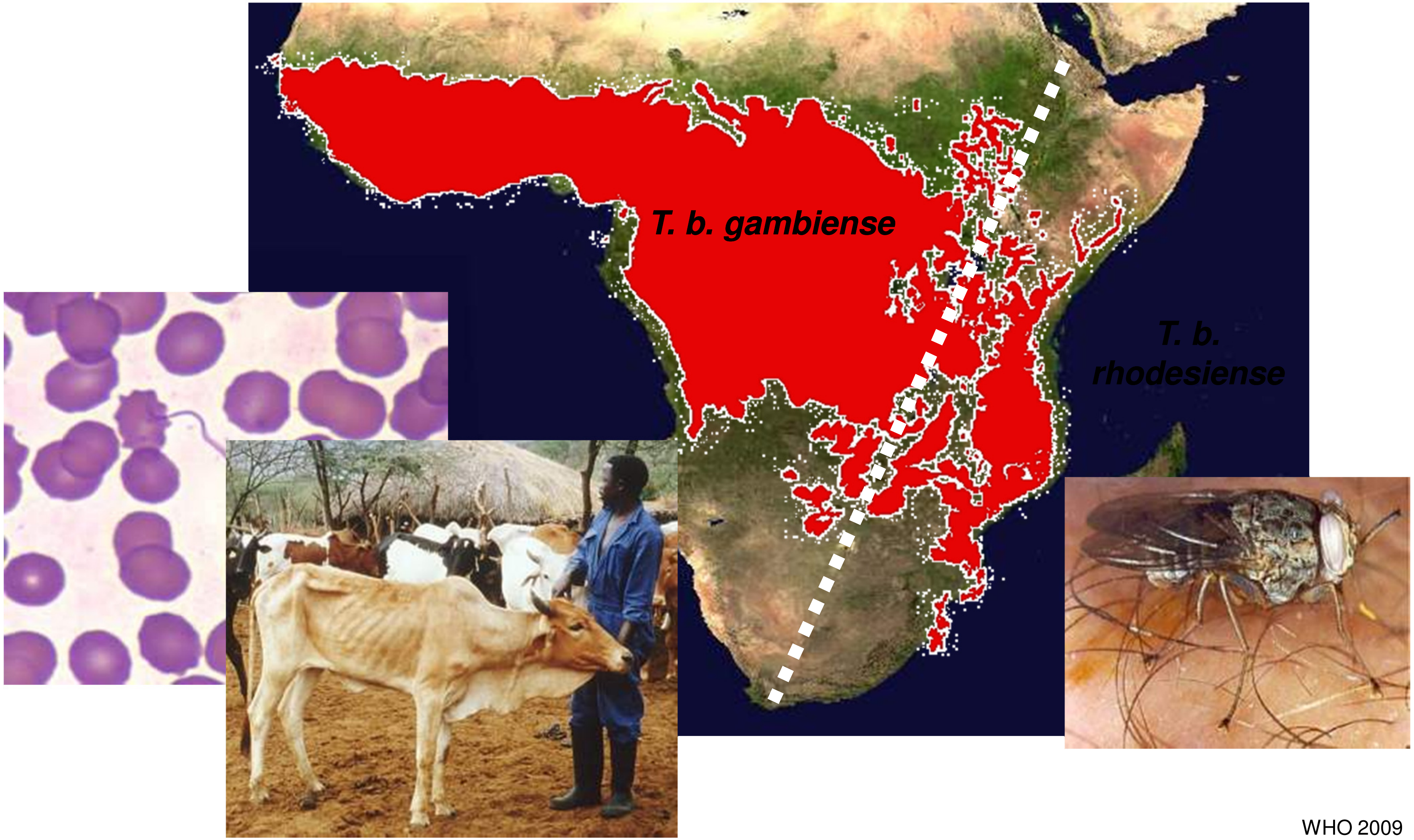
ENSO= global scale pattern of climate variation accounting for up to 40% of temperature and rainfall variation in Pacific



Hales et al., 1999

WHO 2009

Case 4: African Trypanosomiasis



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African Trypanosomiasis

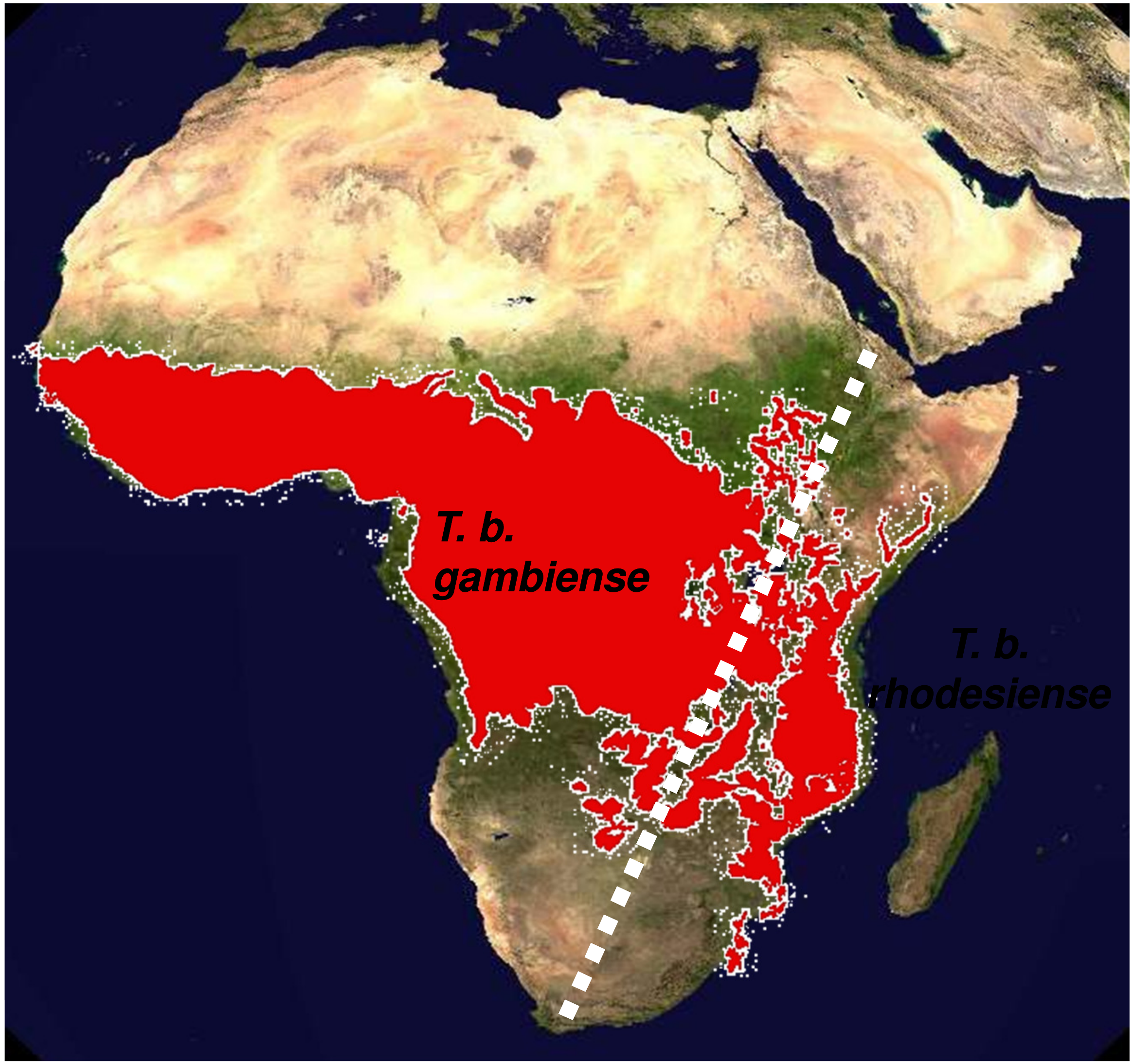
Trypanosomiasis

- **Trypanosomosis, spread by tsetse flies, imposes a huge burden on African people and livestock**
- **Many aspects of the vectors' life cycles are sensitive to climate, and spatial distributions can be predicted using satellite-derived proxies for climate variables**

Source: David Rogers, Oxford

African Trypanosomiasis Distribution

WHO, 2008a



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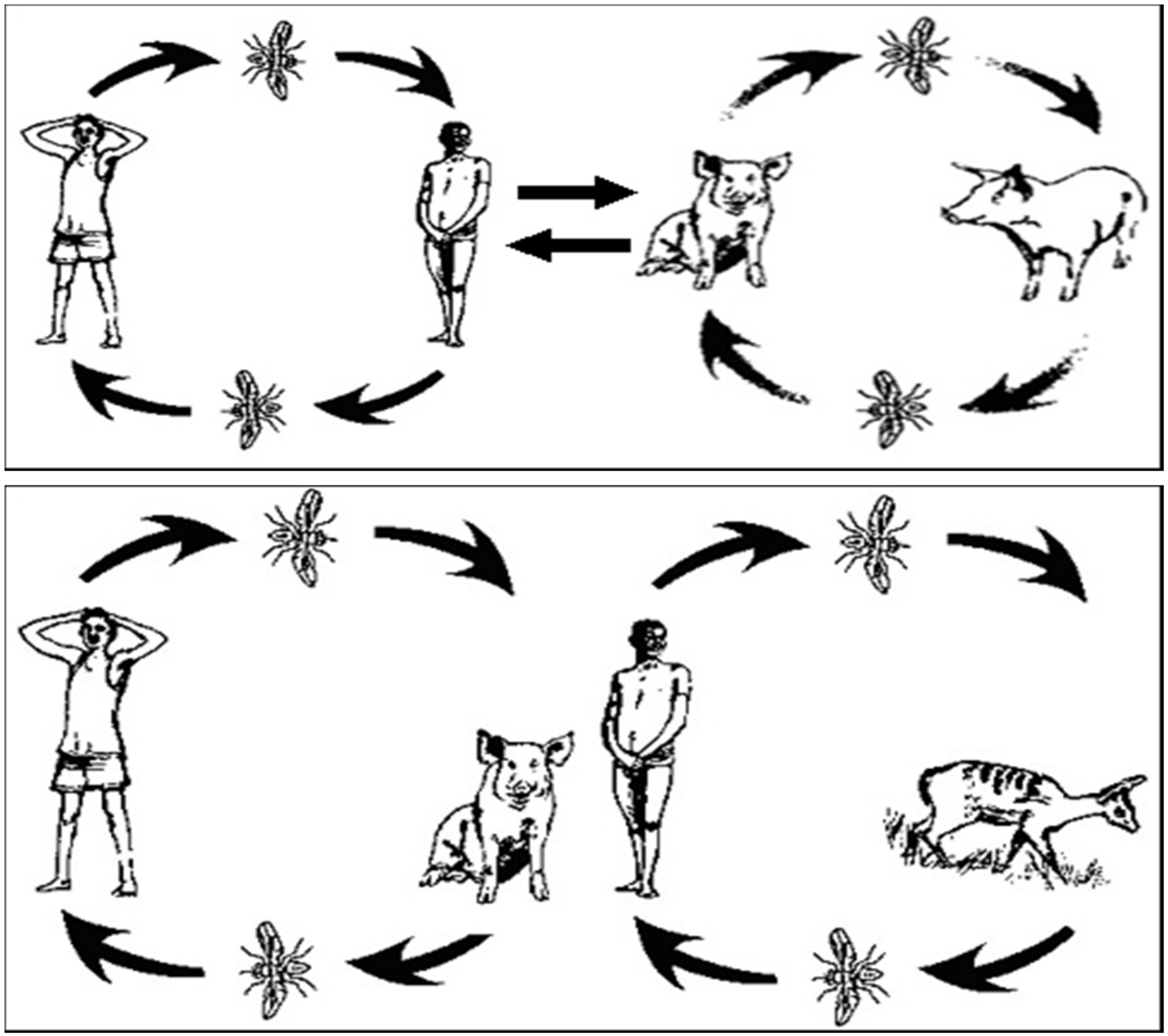
African Trypanosomiasis Transmission



T.b. gambiense

T.b. rhodesiense

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Different Approaches to Modeling

- **Will climate change affect VBD risk?**
  - Focus has been on human-vector-human transmitted diseases (e.g., malaria and dengue)
  - Results of simplified modeling (e.g., Patz et al., 1998; Martens et al., 1999)
    - Climate change could greatly increase numbers of human cases (increase geographic range and altitude)
  - Different results of statistical pattern matching (e.g., Rogers and Randolph, 2000)
    - Climate change could have a small effect on numbers of human cases (small changes to geographic range/altitude)

Limitations of Statistical Models

- **Data quality and potential misclassification**
- **Explanatory variables climatic, land use (NDVI) and Fourier transformations (data dredging?)**
- **Pattern matching using "known" current distribution does not = "ecological" niche**
- **Ecological niche + societal-human factor → potential misclassification (false negatives)**

Limitations of Statistical Models (cont.)

- Cannot use this model to obtain climate change projections and say that the effects of climate change are negligible
- Need to model climate change effects on ecological and societal-human factors simultaneously

Future Outlook?

- Two approaches (simple analytical model and statistical pattern matching) show different projected degree of effect of climate change on human-vector-human VBD risk
- The ideal is mechanistic models of transmission but these require a high number of parameters and detailed knowledge of the ecology of the diseases
- Both are useful techniques in assessing risk, but for human-vector-human VBD we need more “layers”

Future Outlook? (cont.)

- **Both techniques may be more useful (side-by-side) for projections of risk of VBD**
- **Need to develop risk maps using the precautionary principle (worst case) and overlay these with mitigating factors or conservative estimates**

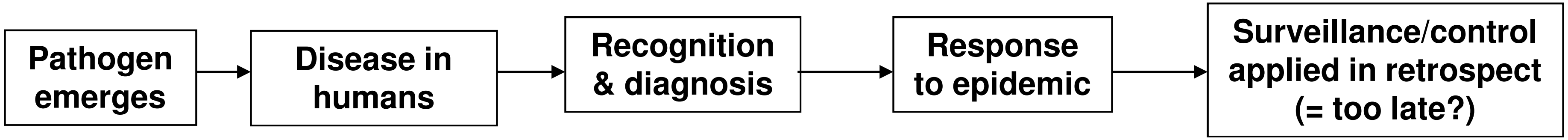
Perspective

- Potential associations with climate but causality difficult to confirm
- Need to consider non-climatic contributing factors
- Very long future time scale
- Data needed for accurate projections not readily available
- Further empirical field work required to improve projections
- Nevertheless, opportunities exist for human adaptation


Opportunities for Adaptation

- Surveillance
- Precautionary approach
- Mainstreaming response
- Enhancing health system capacity
- Anticipating new and emergent pathogens changing VBD burden

A New Approach to Risk Assessment



WHO 2009

Adaptations Include

- **Precautionary approach to risk assessment**
- **Increased surveillance and monitoring (baseline + changing incidence)**
- **Improved tools for integrative risk assessment**
- **“Mainstreaming” through increased health system capacity**
- **Preparedness for new and emergent pathogens**

WHO 2009

Future Directions

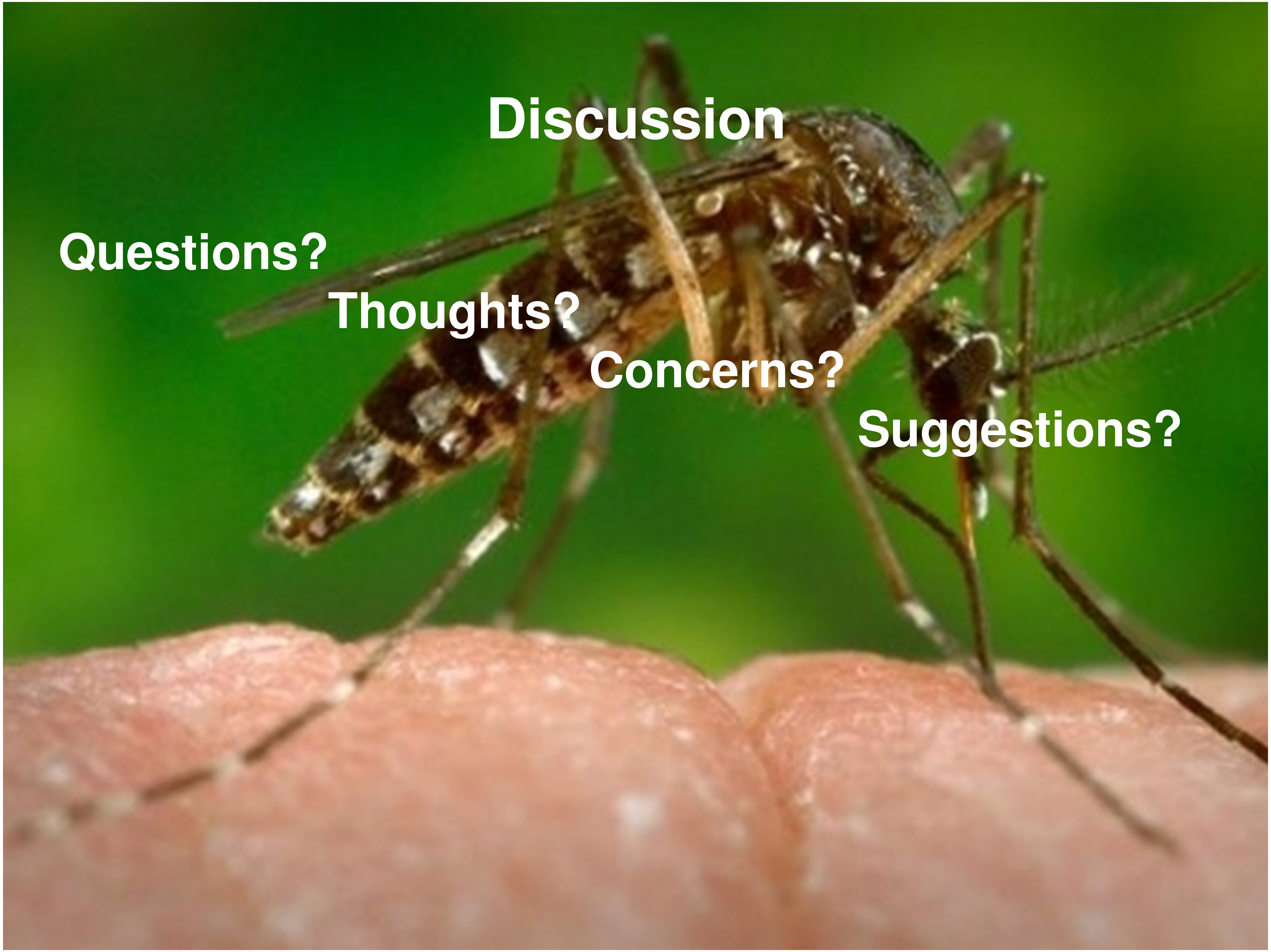
- **Vector-borne infections are intricately linked to the global environment**
- **Climate change has significant potential to change the epidemiology of these diseases**
  - **Disease prevention planners need to be aware of these changing risks**
  - **Researchers need to undertake new multidisciplinary approaches**
  - **New partners need to be invited to participate**

Conclusions

- **Climate change will affect the distribution and incidence of some VBDs globally**
- **Impacts will vary from region to region**
- **Current evidence suggests impacts on some diseases may already be occurring**
- **Risk assessments constrained by complex transmission cycles and multiple determinants**

Conclusions (cont.)

- **Current models produce differing results**
- **Non-climatic factors remain important determinants of risk**
- **Impacts may include unanticipated emergence of new pathogens**


Discussion
Questions?
Thoughts?
Concerns?
Suggestions?

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