Climate Change and Vector-Borne/Zoonotic Diseases

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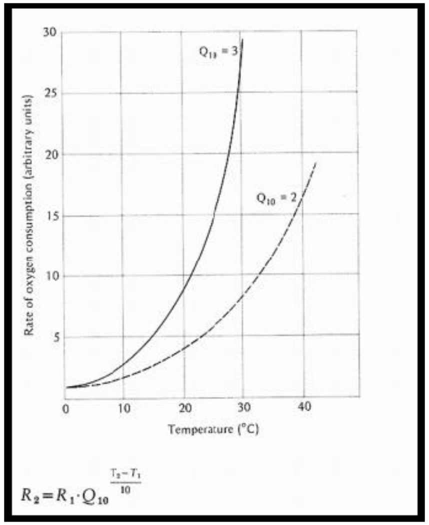
Effects of Climatic Factors on Hosts and Vectors*

- Growth, development and reproduction
  - Q_{10} effects (approximate doubling of metabolic rates in poikliothermic organisms with 10ºC rise in temperatures)
  - Rate of reproduction/Number of generations per season
  - Example: *Anopheles gambiae* gonotrophic cycles significantly shorter in open treeless sites (warmer) than forested sites (cooler)
- Activity patterns
  - Feeding
  - Host seeking
  - Mate seeking etc.
- Availability of breeding sites
- Survival
  - Severe weather events
  - Tolerance limits for vectors and hosts
  - Food or water availability
  - Freezing or heat stress

Vector	Disease agents	Threshold for Biological Activity
Anopheles mosquitoes	*Plasmodium sp.*	8-10º C
Triatomine bugs	*Trypanosoma cruzi*	20º C (2-6º C for survival)
Aedes mosquitoes	Dengue virus	6-10º C
Ixodes ticks	*Borrelia burdgdorferi, Anaplasma phagocytophilum*, *Babesia microti*	5-8º C
Bulinus and other snails	*Schistosoma sp.*	5º C (25±2º C optimal)

Source: Patz and Olson 2006

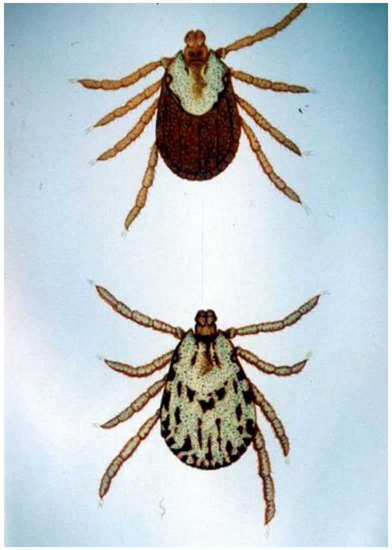
Effect of Temperature on Oxygen Consumption



* See Gubler et al. 2001 for citations and additional examples

Climate Effects on Hosts and Vectors
- Distribution and Abundance -

- "Weather school" (Andrewartha and Birch 1954)
  - Changing conditions make areas more or less suitable for survival and reproduction, which affects abundance of different species
  - Changing conditions often related to climatic variables (temperature, precipitation, humidity, etc.)
  - Most extreme effects seen for insects and other arthropods
- Host or vector populations can increase during favorable conditions and later crash as conditions deteriorate
- Many examples with epidemiologic significance
  - Mosquito vectors
    - Rift valley fever (arbovirus)(Linthicum et al. 1999)
    - Malaria (protozoal)
  - Small mammal hosts
    - Deer mice and SNV (Yates et al. 2002)
    - Gerbils and plague (Kausrud et al. 2007)
  - Ticks
    - *Ixodes ricinus* (Sweden)(Lindgren, Talleklint and Polfeldt 2002, Talleklint and Jaenson 1998)
    - *Dermacentor variabilis* (Colorado) (Eisen, Meyer and Eisen 2007)



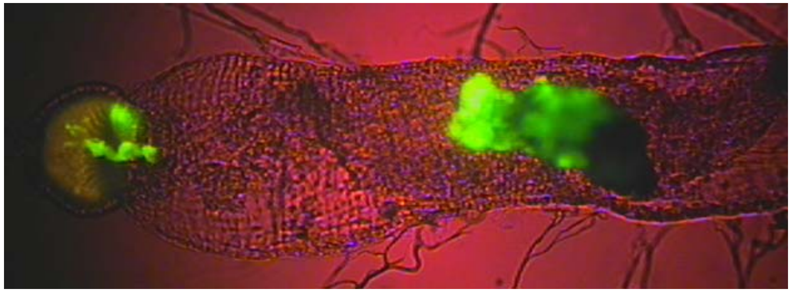
Climatic Effects on Pathogen Development

- Extrinsic incubation periods
- Infectivity
- Ability to maintain development in vector

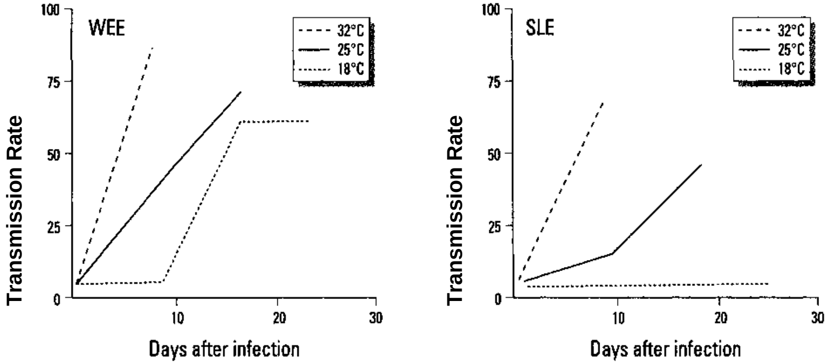
Effect of Temperature on Blocking of Fleas by *Yersinia pestis* and Mortality among Infected Fleas

Yersinia pestis **Strain**	**Percent of fleas blocked at given temperature**			**Percent flea mortality at given temperature**		
	20ºC	**25ºC**	**30ºC**	**20ºC**	**25ºC**	**30ºC**
195-P-wt	32	13	0	42	41	70

Source: Hinnebusch, Fischer and Schwan 1998

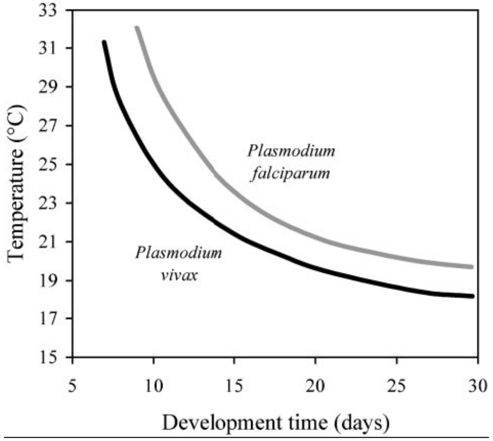


Effect of Temperature on Viral Transmission by *Culex tarsalis*



Source: Reeves et al. 1994

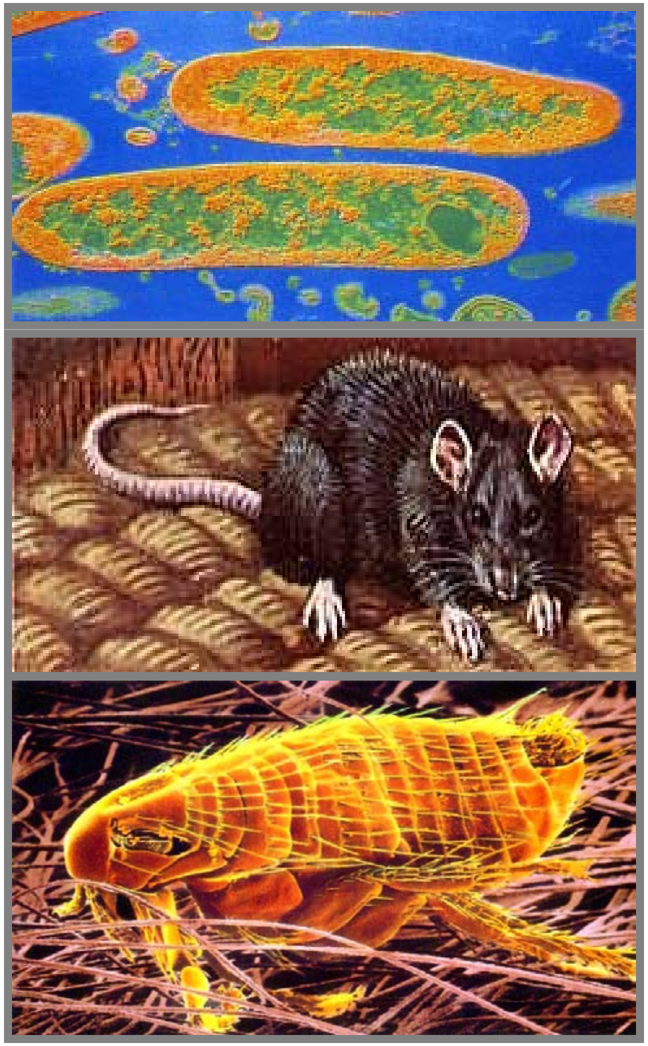
Effect of Temperature on Extrinsic Incubation Period of *Plasmodium sp.* in *Anopheles* mosquitoes



Source: McDonald 1957

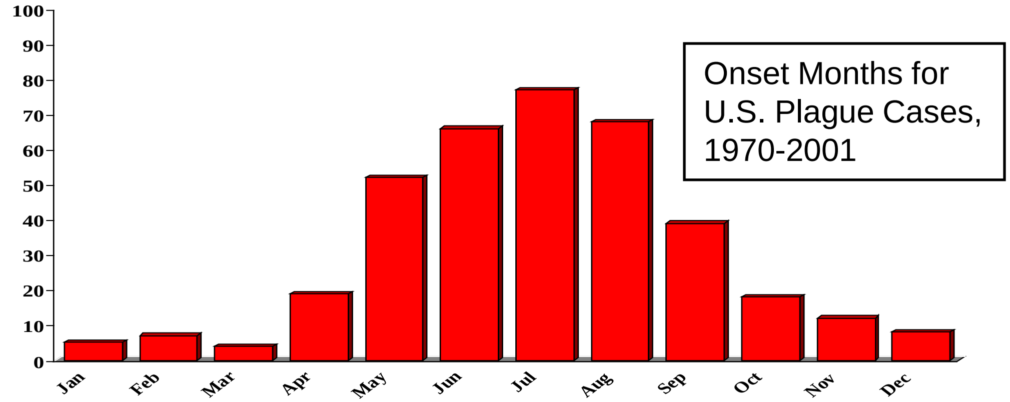
Climatic Variability and Plague

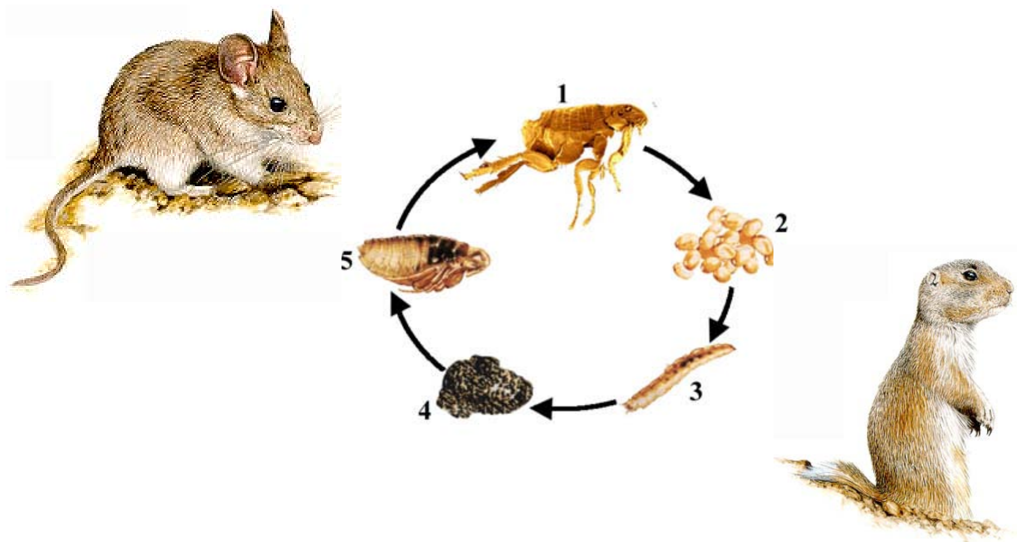
- **Major Pandemics (Justinian's Plague, Black Death and Modern Pandemic) were associated with major climatic fluctuations**
- **Parmenter et al. (1999), Enscore et al. (2002) – Frequency of human plague in American Southwest affected by temperature and humidity**
- **Stenseth et al. (2006) – plague epizootics in gerbils**
- **Collinge et al. (2005) – plague epizootics in prairie dogs**
- **Winter-spring precipitation important in the above studies**
- **Summer temperatures, precipitation and humidity also important in some models**

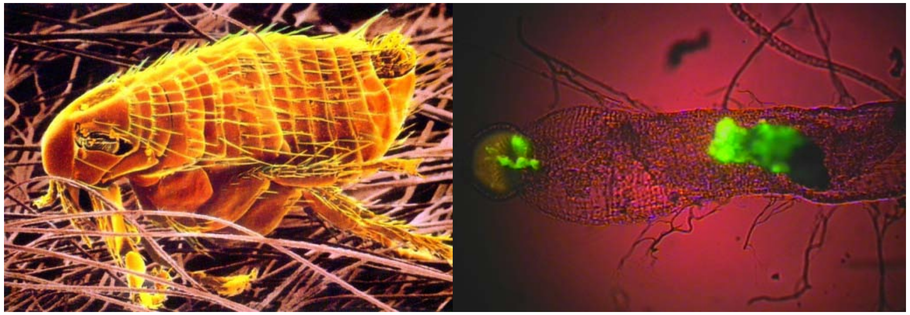


How Could Climatic Variables influence Plague Activity?

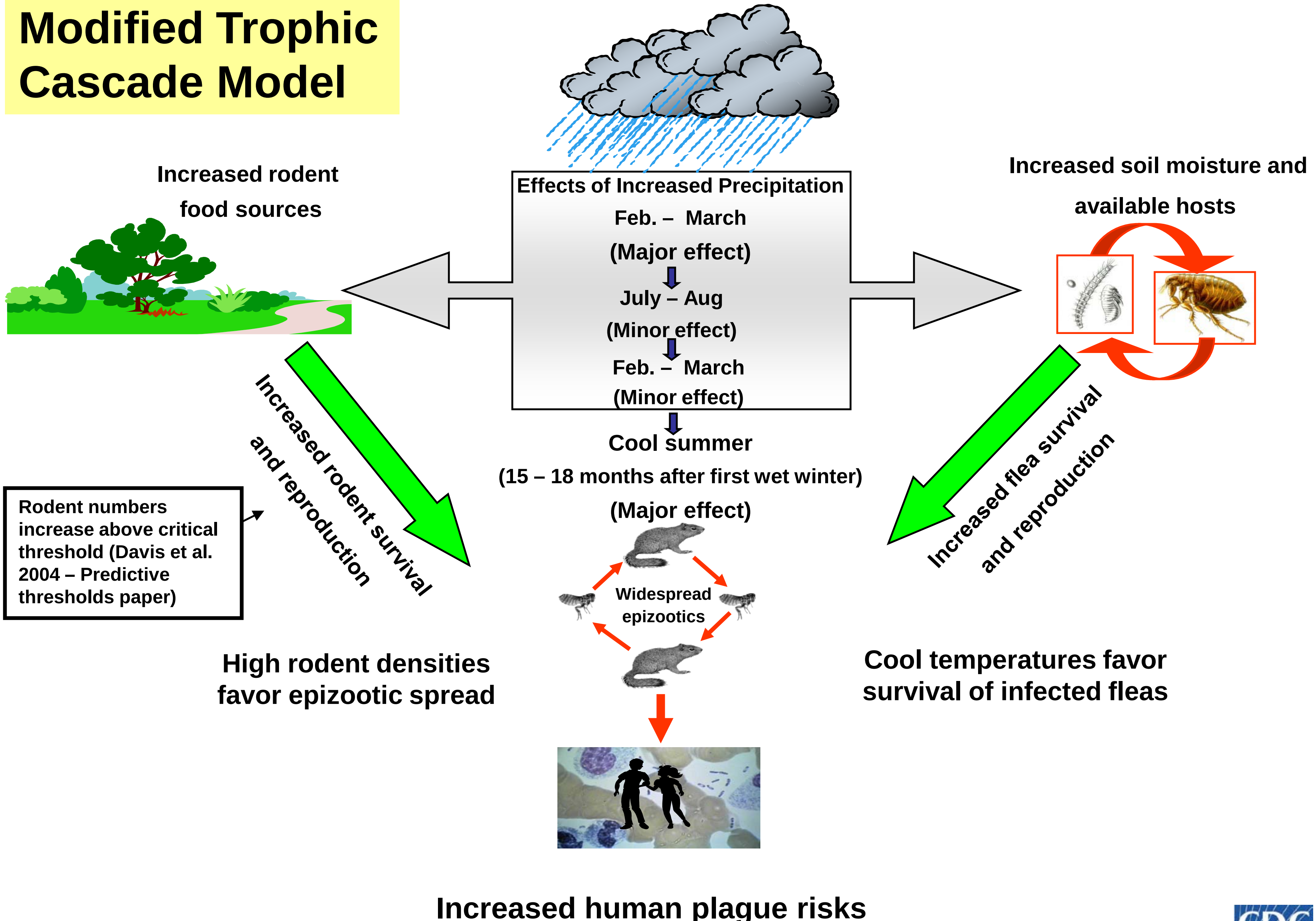
- **Seasonality of transmission**
- **Survival of fleas**
- **Ability of fleas to transmit and retain infection**
- **Blockage of flea foregut by *Y. pestis* biofilm is disrupted at temperatures > 27.5º C – (Blocked fleas transmit more efficiently)**
- **Extrinsic incubation periods (Time between when fleas become infected and when they can transmit.)**
- **Rodent host and flea vector population dynamics (Trophic cascade model)**





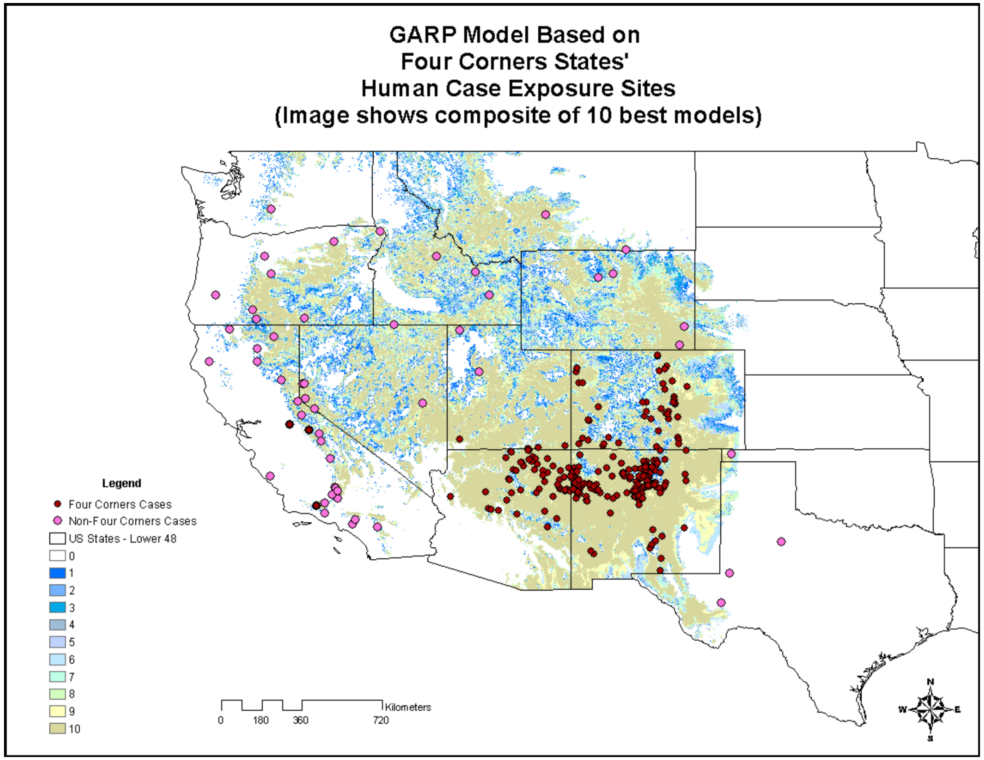


Modified Trophic Cascade Model



Plague and Climate Change

- Nakazawa et al. (2007, VBZD) evaluated spatial patterns of plague transmission using four different general circulation models of project climate change
- Concluded that some shifting of transmission sites would occur but changes will be subtle with general northward movement of areas of high transmission
- Effect on the number of human plague cases hard to predict



Climate and Vector-Borne Diseases
- Malaria -

- African malaria epidemics triggered by climate anomalies that follow periods of drought (DeSilva et al. 2004)
- Dec-Feb rainfall totals explain > two-thirds of variation in Botswana cases
- Sea surface temperatures linked to rainfall and El Nino-La Nina cycles (Thomson et al. 2005, 2006)
- Other climatic anomolies linked to malaria epidemics in
  - Colombia (Poveda et al. 2001)
  - Indian subcontinent (Bouma and van der Kaay 1994)
  - Southern Africa - Incidence correlated with pos. SOI (La Nina periods) (Mabaso et al. 2006, 2007a, b)
  - Uganda – Incidence linked to El Nino cycles (Lindblade et al. 1999)
  - South Africa – Maximum daily temperatures from preceding season correlated with malaria cases (Craig et al. 2004)
  - Ethiopia – Minimum temperatures (< 12^{o}C) in cold region correlated with cases
  - Kenya and Ethiopia – Heavy rainfall associated with outbreaks (Lindsay and Martens 1998)
  - Burkina Faso – Temperature best predictor of clinical malaria in children under 5 years (Ye et al. 2007)

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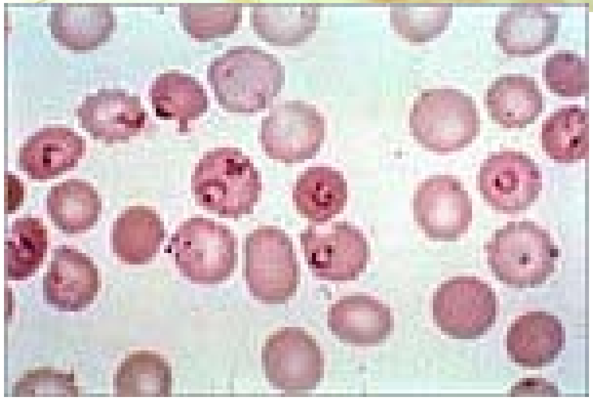
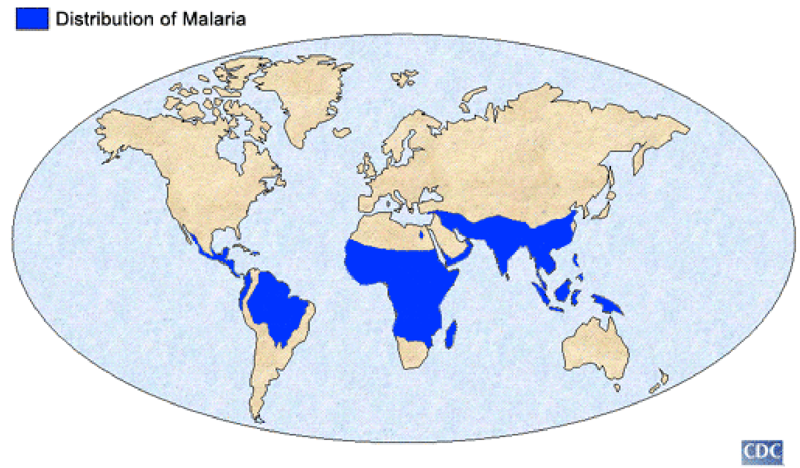
Projected Effects of Climage Change
- Malaria -

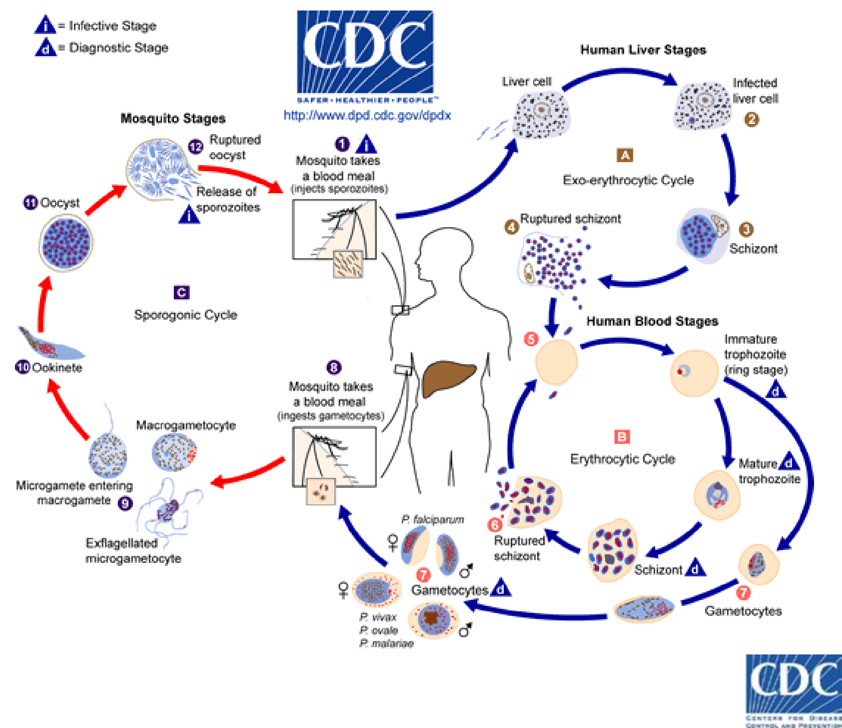
- Many have suggested that global warming will result in a northward shift of vectors and increased malaria risks for those in temperate regions
- Small, Goetz and Hay (2003)
  - Incidence in Africa would increase in some areas and decrease in others
- Tanser, Sharp and le Sueur (2003)
  - 16-28% increase in person-months of exposure
  - Little latitudinal change in risk – most change occurs in existing areas or with altitude



Climate and Vector-Borne Diseases - Malaria -

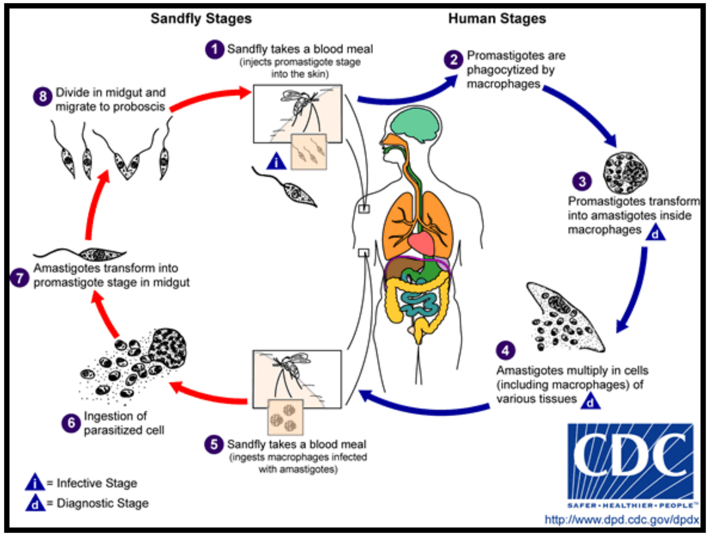
- Others failed to find links between climate and malaria incidence/outbreaks
- Reiter et al. (2004)
  - Stressed local effects and other factors that could be confounded with climate effects.
  - Felt Tanser et al. (2003) used too few points were used to draw continent-wide conclusions on future transmission risks
  - Disagreed with how Tanser et al. (2003) used the term stable and its implication for where outbreaks would occur
- Hay et al. (2002) – No association between long-term meteorological trends and malaria outbreaks in East Africa
- Dev (2007) – No association between rainfall and annual incidence of malaria in India.
- Haile (1989) – Possible US transmission
  - *Anopheles quadrimaculatus* still abundant in formerly malarious regions of US but established foci of malaria no longer exist in this country
  - Would climate change lead to reestablishment of malaria in U.S.?

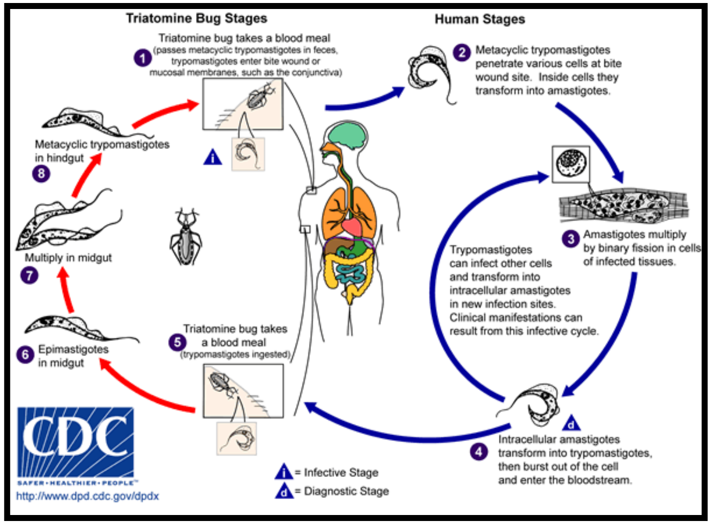




Climate Change
- Parasites other than Malaria -

- Cases of cutaneous leishmaniasis correlated with drought, temperature, multivariate ENSO index (Franks et al. 2002, Thompson et al. 2002, Cardenas et al. 2006, Cardenas and Pascual. 2006)
- Distribution of Chagas disease vectors associated with high temperatures, low humidities and certain types of vegetation (Carcavallo 1999, Lorenzo and Lazzari 1999, Dumonteil et al. 2002)



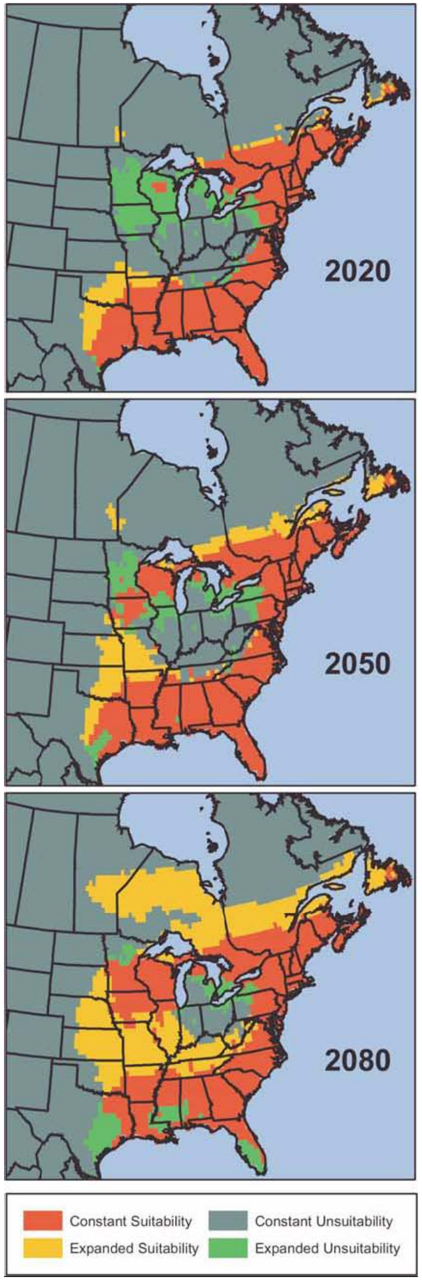


Climate and Vector-Borne Diseases
- Lyme Disease -

- Water stress and temperature regulate off-host mortality for *I. scapularis* (Needham and Teel 1991, Bertrand and Wilson 1996)
- 98% of *I. scapularis* life cycle occurs in off-host environments (Brownstein, Holford and Fish 2005) – High likelihood for climate factors to effect survival and reproduction

Climate and Vector-Borne Diseases
- Lyme Disease -

- *Ixodes* tick life cycles and activity patterns known to be affected by temperature, humidity and rainfall
- Brownstein, Holford and Fish (2005) used climate-based logistic regression models to explain current distribution of *I. scapularis* in North America
- Used above model to extrapolate changes in distribution based on climate change predictions
- Expanded habitat suitability in Canada
- Decreased suitability in southern U.S.



Brownstein, Holford and Fish. Ixodes scapularis hability suitability and projected future Lyme risks – EcoHealth 2, 38-46, 2005

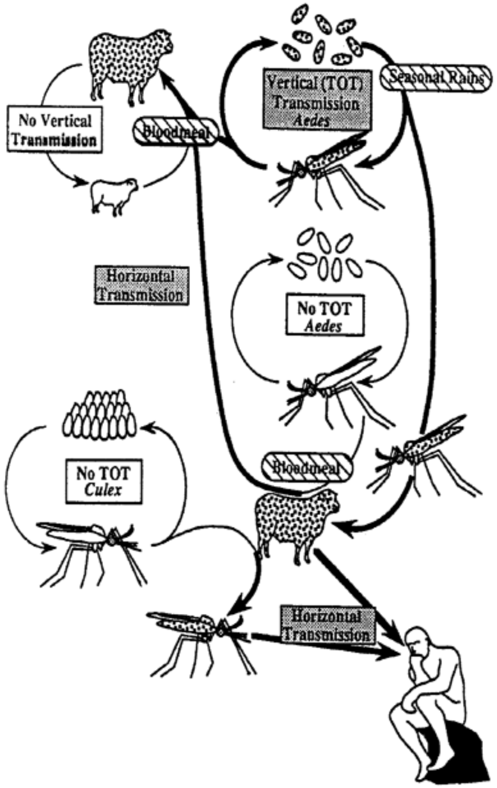
Climate and Zoonotic Diseases
- Tick-Borne Encephalitis -

- Randolph and Rogers (2000) modeled TBE distribution in Europe
- Used above model and GCMs to project future distribution of TBE
- Summer temperature rises and decreases in moisture should drive TBE into higher latitude or higher altitude sites
- Eventually TBE might occur only in a small part of Scandinavia with new foci in southern Finland
- Changes likely to be due to disruptions in tick seasonal dynamics
- Sumilio et al. (2007)
  - Spring-time daily max temperatures have increased since 1989
  - But other factors likely to be more important in occurrence of TBE

Climate and Vector-Borne Diseases - Rift Valley Fever -

- RVF outbreaks associated with periods of heavy rainfall in enzootic regions (Meegan and Bailey 1988, Wilson et al. 1994, Digoutte and Peters 1989, Linthicum et al. 1999)

- Linthicum et al. (1999) – Remote sensing can be used to observe flooding of dambos and forecast outbreaks

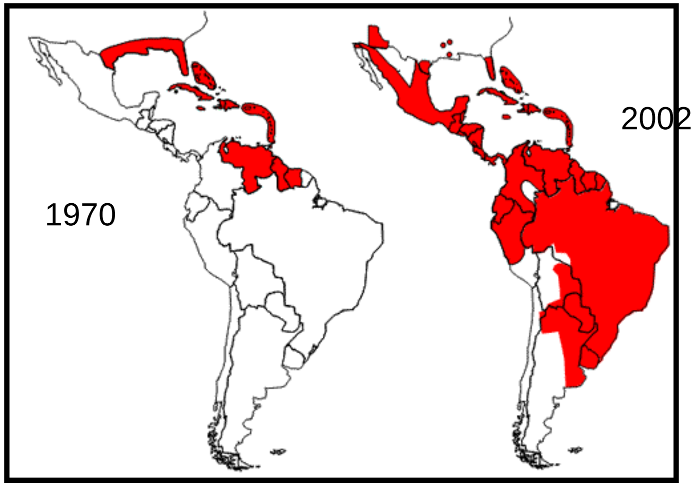


Source: Wilson 1994 Ann NY Acad Sci.

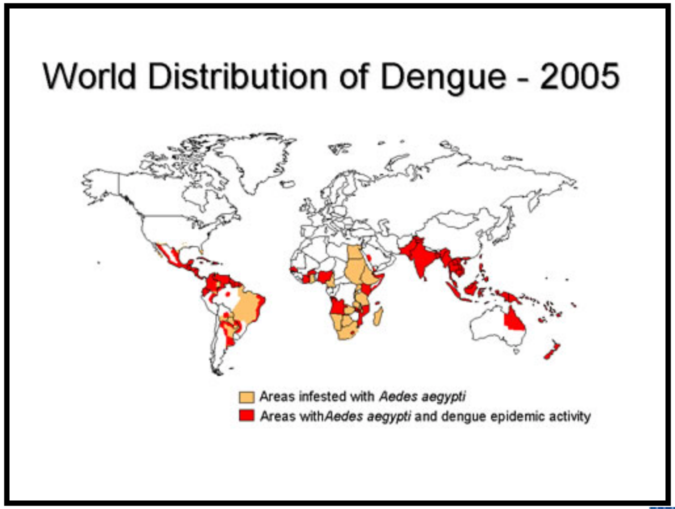
Climate and Zoonotic Diseases
- Dengue -

Transmission and distribution influenced by climatic factors

- Freezing temperatures kill overwintering eggs and larvae of *Aedes aegypti* (Chandler 1945)
- Temperature affects pathogen replication, maturation and length of infectivity in vector (Reiter 1988, Watts et al. 1987)
- Dengue epidemics correlated with rainfall in Trinidad (Chadee et al. 2006)
- Wu (2007) dengue incidence in Taiwan negatively correlated with monthly temperature deviation and relative humidity

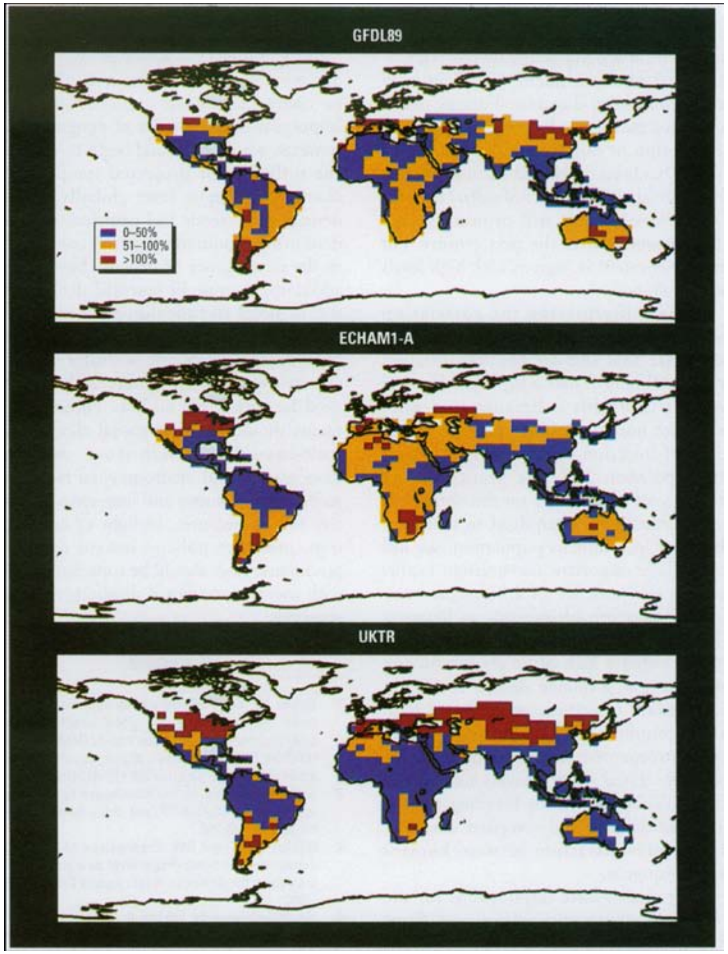


Aedes aegypti distribution in 1970 and 2002



Climate and Vector-Borne Diseases - Dengue -

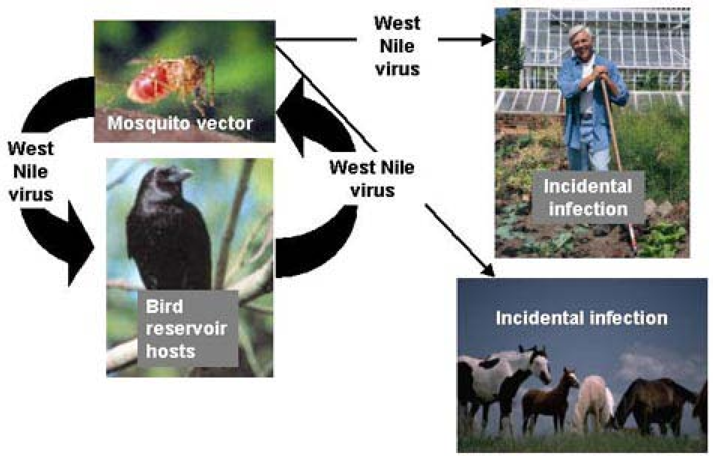
- Jetten and Focks (1997) – Increasing temperatures will increase length of transmission season in temperate regions
- Patz et al. (1998) used simulation analyses to link temperature outputs from three general circulation models (GCM) to a dengue vectorial capacity equation
  - Predicted temperature-related increases (averages of 31-47%) in potential seasonal transmission
  - Predicted risks would initially increase near edges of current distribution
  - Also predicted that endemic areas would be at more risk of DHF as transmission intensity increases
- Will dengue spread in continental US?
- Possible lessons from outbreaks along US-Mexico border (suitable climatic conditions on both sides of border but no outbreak on U.S. side)

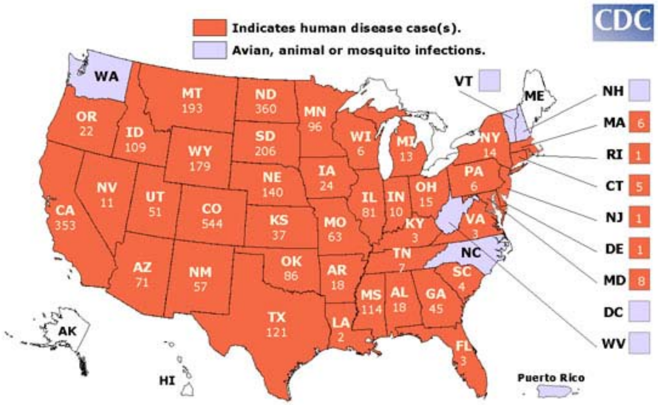


Climate and Zoonotic Diseases - West Nile Virus -

- Minimum temperature was major climatic favoring earlier appearance of disease (Paz 2006)
- Cases more closely correlated with extreme heat than high humidity
- Proposed early extreme rise in summer temperatures is a good indicator of increased vector populations
- Outbreaks in Romania (1996) and New York City (1999) also occurred after summer heat waves
- Abundance of potential West Nile vectors in Washington state correlated with temperature (Pecoraro et al. 2007)

West Nile Virus Transmission Cycle



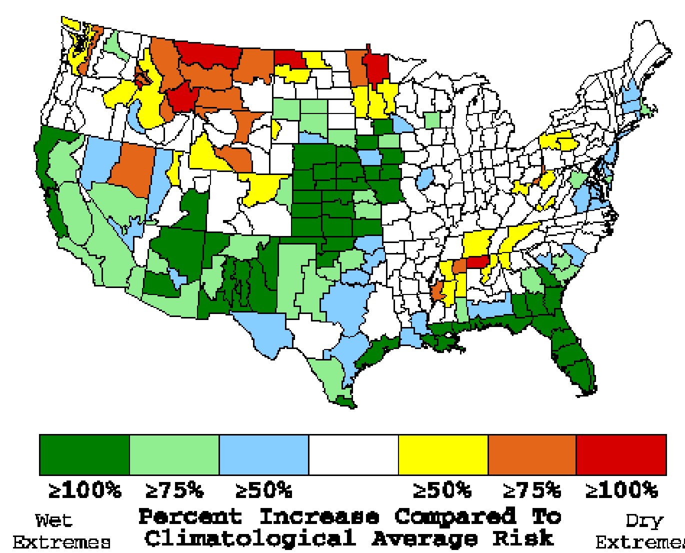


2007 West Nile Virus Activity as of 10/23/07

Climate and Zoonotic Diseases
- Hantavirus -

- High rodent densities should increase
  - hantavirus transmission
  - likely human contact (invasion of homes, etc.)
- Trophic cascade hypothesis (Yates et al. 2002)
- In southwestern USA El Nino events result in high precipitation that might lead to
  - Increased availability of rodent food sources
  - Increased rodent reproduction and survival
  - Increase in human HPS cases
- Relationships between climatic variables, deer mouse numbers, hantavirus prevalence in mice and the occurrence of increased human cases is complex and can vary from region to region (Mills 2005)

DJF Precipitation Extremes During El Nino
Risk of Extreme Wet and Dry Years

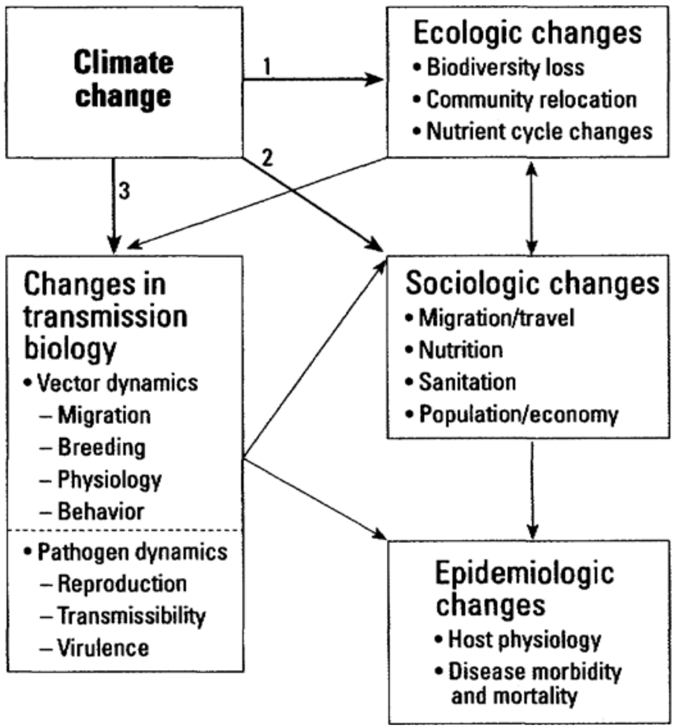


Predicting the Effects of Climate Change on Vector-Borne or Zoonotic Diseases

- Incomplete knowledge and few long-term studies
- Ecological cycles are complex and vary between regions
- Many confounding factors of human origin
  - Land-use patterns
  - agricultural and industrial development
  - water management
  - cultural and behavioral factors, etc.

- Many global changes appear to be occurring (Sutherst 2004 and others)
  - Climate
  - Atmospheric composition
  - Urbanization
  - Land use, landcover, and biodiversity
  - Trade and travel
  - Civil unrest and unstable governments
  - Other factors

- Global climate change likely to present emerging disease threats



Assessing effects of climate change on vector-borne diseases

Source: Data from Chan et al. 1999; Figure in Gubler et al. 2001

Responding to Possible Climate Change

- Long-term ecological and epidemiological research on influence of environmental changes on disease cycles
- Enhanced surveillance
  - Appearance of human cases in previously disease-free areas
  - Introduction of new vectors, hosts, or pathogens
  - Changing transmission patterns in existing foci
- Strengthen public health infrastructure to improve recognition and response
- Identify potentially vulnerable populations
- Maintain awareness of other changes that could interact with climate changes to result in emerging disease risks
- Measures to reduce the spread of disease or disease vectors and hosts
- Review, evaluate and prepare countermeasures (vaccines, therapeutic agents, insecticides, etc.)