Vector movements and climate
Impacts on vector-borne diseases

AUSTRALIAN ANIMAL HEALTH LABORATORY
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Overview

- Climate
  - Predicted trends
  - Reviews of impact on vector-borne diseases
  - Impacts on vectors, host
- Other factors
- Long-distance dispersal
  - Windborne
- An example - bluetongue in Europe

Climate Change Trends

Phenomenon	Current trend	Likelihood of future trend for 21st Century (Special Report on Emmissions Scenarios)
Air temperatures, day and night	Warmer and fewer cold periods	Virtually certain (>99% probability)
Warm spells & heat waves	More frequent	Virtually certain
Heavy precipitation events	Increased frequency in most areas	Very likely (90-99% probability)
Area affected by drought	Increased in some areas	Likely (66-90% probability)
Intense tropical cyclone activity	Increased	Likely
Incidence of extreme high sea levels	Increased	Likely

Impacts on Vector-borne diseases

Climate-related drivers of impacts										Level of risk & potential for adaptation
Warming trend	Extreme temperature	Drying trend	Extreme precipitation	Precipitation	Snow cover	Damaging cyclone	Sea level	Ocean acidification	Carbon dioxide fertilization	Potential for additional adaptation to reduce risk; Risk level with high adaptation; Risk level with current adaptation

Central and South America

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation (Very low – Medium – Very high)
Water availability in semi-arid and glacier-melt-dependent regions and Central America; flooding and landslides in urban and rural areas due to extreme precipitation (*high confidence*) [27.3]	• Integrated water resource management • Urban and rural flood management (including infrastructure), early warning systems, better weather and runoff forecasts, and infectious disease control	Warming trend, drying trend, snow cover, extreme precipitation	Present	
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	
			Long term (2080–2100) 4°C	
Decreased food production and food quality (*medium confidence*) [27.3]	• Development of new crop varieties more adapted to climate change (temperature and drought) • Offsetting of human and animal health impacts of reduced food quality • Offsetting of economic impacts of land-use change • Strengthening traditional indigenous knowledge systems and practices	Extreme temperature, extreme precipitation, carbon dioxide fertilization, precipitation	Present	
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	
			Long term (2080–2100) 4°C	
Spread of vector-borne diseases in altitude and latitude (*high confidence*) [27.3]	• Development of early warning systems for disease control and mitigation based on climatic and other relevant inputs. Many factors augment vulnerability. • Establishing programs to extend basic public health services	Warming trend, extreme precipitation, extreme temperature, precipitation	Present	
			Near term (2030–2040)	
			Long term (2080–2100) 2°C	not available
			Long term (2080–2100) 4°C	not available

Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; 2014

CSIRO

Climate change: impact on the epidemiology and control of animal diseases
Scientific and Technical Review 27 (2) 2008

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- How the biodiversity sciences may aid biological tools and ecological engineering to assess the impact of climatic changes
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- Climate change and mosquito-borne disease: knowing the horse before hitching the cart
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- Global change: impact, management, risk approach and health measures – the case of Europe
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- Managing animal disease risk in Australia: the impact of climate change
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Effect of climate change on vector-borne disease risk in the UK (Medloch & Leach, 2015)

	Current situation	Temperature-change assessment (+2°C)*	Confounders
Dengue virus or chikungunya virus	Main vectors are invasive mosquitoes, such as *Aedes albopictus*, expected to colonise UK in the future, and *Aedes aegypti*, less able to survive through UK winter; under a current climate scenario, *A albopictus* would be able to survive across large parts of England and Wales (up to 18 weeks elapsing between egg hatching in spring and autumn diapause of eggs, and up to 27–32 weeks between egg hatching and adult die off)[3]	Climate assessments suggest that UK climate is now suitable for *A albopictus*; climate change assessments for UK and Europe predict that southeast England will become more suitable for the establishment of *A albopictus*; an increased activity period of 1–2 weeks is expected for adult *A albopictus* in southern England by 2030–50, based on a 1°C annual temperature rise, and a 3–4 week extension of activity is expected for a 2°C annual temperature rise; an overall climate suitability increase of 15% by 2030–50 is expected, based on 1°C annual temperature change, and a suitability increase of 25–30% is expected, based on a 2°C annual temperature change); more than 80% agreement between Regional Climate Models;[4] climate change models for chikungunya predict suitable temperatures for 1 month of chikungunya virus transmission in London by 2041 and 1–3 months of virus transmission across most of southeast England by 2071–2100;[5,6] dengue risk will largely be linked to colonisation by *A aegypti*, which is not expected to become established up to 2100, and therefore the main dengue virus risk might come from *A albopictus*	Mosquitoes need to be imported by used tyres, or in vehicles from endemic areas; once established, they will colonise urban areas, and abundance will be proportionate to increasing temperatures and precipitation; however, the effect of peri-urban water storage would need to be considered
West Nile virus	UK has several endemic mosquito species that could potentially act as vectors; mainly *Culex* spp mosquitoes, including recently discovered species (*Culex modestus*); West Nile virus transmission is not considered climatically limited; absence of transmission might be due to low mosquito abundance for sustained transmission and, until recently, a restricted distribution of human biting *Culex* spp mosquitoes	Climate change would affect the biology and available habitats for mosquitoes, although other factors would need to be considered in a model; a 2°C increase in temperature would affect endemic mosquitoes by shortening their gonotrophic cycle and bloodmeal digestion, thus increasing abundance and shortening generation times, leading to increased cohorts of multivoltine species; there are no models to quantify this, however some data is available for some endemic *Aedes* species:[7,8] larval/pupal development lasts 38 days at 8°C and 18–20 days at 12°C; bloodmeal digestion lasts 30 days at 4°C, 14 days at 8°C, and 5 days at 20°C; embryonic development lasts 42 days at 4°C, 22 days at 12°C, and 8 days at 20°C	Climate change adaptation promotes wetland creation in coastal, rural, and urban locations; some of these will exacerbate *Culex* spp populations, human biting by a range of mosquito species, and increase in exposure to potential transmission cycles; birds would need to be infected to sustain transmission
Malaria	UK anophelines are considered competent vectors, although some species are now less anthropophilic; climate modelling has confirmed that transmission of *Plasmodium vivax* (and to a lesser degree *Plasmodium falciparum*) could already occur in the UK, although no cases are reported	Increasing temperatures will directly affect the parasite's development in the mosquito; one of five malaria effect models under the most extreme scenarios consistently predicts climate in southern England suitable for sustained *P falciparum* transmission (>1 month) by 2080, whereas another model predicts some suitability by 2030s; however, the other models predict no suitability, even by 2080; under medium–high scenario, a *P vivax* model[9] predicts that southern Great Britain will be climatically suitable for 2 months of the year by 2030 and for 4 months in parts of southeast England; by 2080, regions as far north as southern Scotland will be climatically suitable for 2 months, with 4 months suitability in southern Great Britain[10]	Human beings would have to sustain transmission as malaria is not zoonotic; antimalarials and public health care would minimise transmission to local cases
Lyme disease	Already endemic with more than 1000 confirmed cases each year; complex transmission cycle with positive and negative seasonal effects on tick activity from increasing temperature; tick seasonal activity is affected by changes	Increasing temperatures will change the seasonal activity of ticks to earlier and later in the season, with reduced activity in the summer; a latitudinal and altitudinal spread is not expected to have a significant effect; evidence of altitudinal spread in central Europe of *Ixodes ricinus* from 700 m, between 1950 and 1980, to 1250 m by 2006; mean annual temperature had increased by 1·4°C between 1961 and	The bacteria causing Lyme disease occurs in a range of wild mammals and wild birds, and models would therefore need to consider the effect of a changing climate on these host species, the seasonality and abundance of the tick, and the interactions between *Borrelia*

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THE IMPACTS OF CLIMATE CHANGE ON HUMAN HEALTH IN THE UNITED STATES; A Scientific Assessment, 2016

Changing Distributions of Vectors and Vector-Borne Diseases

Key Finding 1: Climate change is expected to alter the geographic and seasonal distributions of existing vectors and vector-borne diseases *[Likely, High Confidence]*.

Earlier Tick Activity and Northward Range Expansion

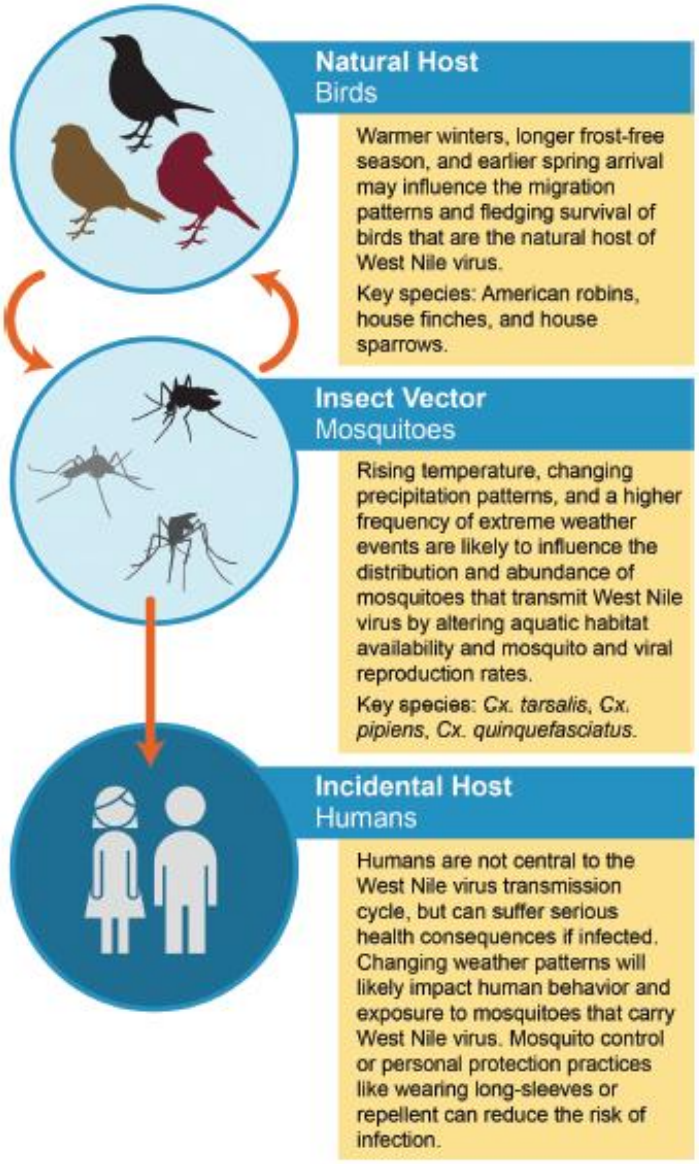
Key Finding 2: Ticks capable of carrying the bacteria that cause Lyme disease and other pathogens will show earlier seasonal activity and a generally northward expansion in response to increasing temperatures associated with climate change *[Likely, High Confidence]*. Longer seasonal activity and expanding geographic range of these ticks will increase the risk of human exposure to ticks *[Likely, Medium Confidence]*.

Changing Mosquito-Borne Disease Dynamics

Key Finding 3: Rising temperatures, changing precipitation patterns, and a higher frequency of some extreme weather events associated with climate change will influence the distribution, abundance, and prevalence of infection in the mosquitoes that transmit West Nile virus and other pathogens by altering habitat availability and mosquito and viral reproduction rates *[Very Likely, High Confidence]*. Alterations in the distribution, abundance, and infection rate of mosquitoes will influence human exposure to bites from infected mosquitoes, which is expected to alter risk for human disease *[Very Likely, Medium Confidence]*.

Emergence of New Vector-Borne Pathogens

Key Finding 4: Vector-borne pathogens are expected to emerge or reemerge due to the interactions of climate factors with many other drivers, such as changing land-use patterns *[Likely, High Confidence]*. The impacts to human disease, however, will be limited by the adaptive capacity of human populations, such as vector control practices or personal protective measures *[Likely, High Confidence]*.



Higher temperatures affect the West Nile virus (WNV) system by

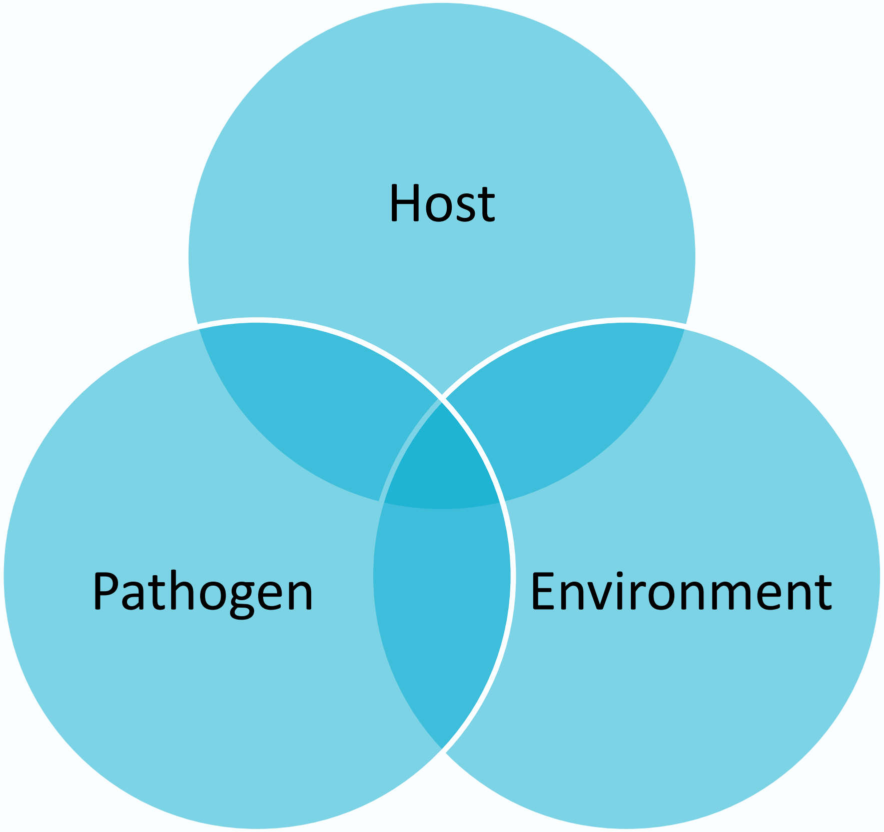
- accelerating mosquito development and virus reproduction,
- increasing egg-laying and biting frequency,
- affecting mosquito survival.

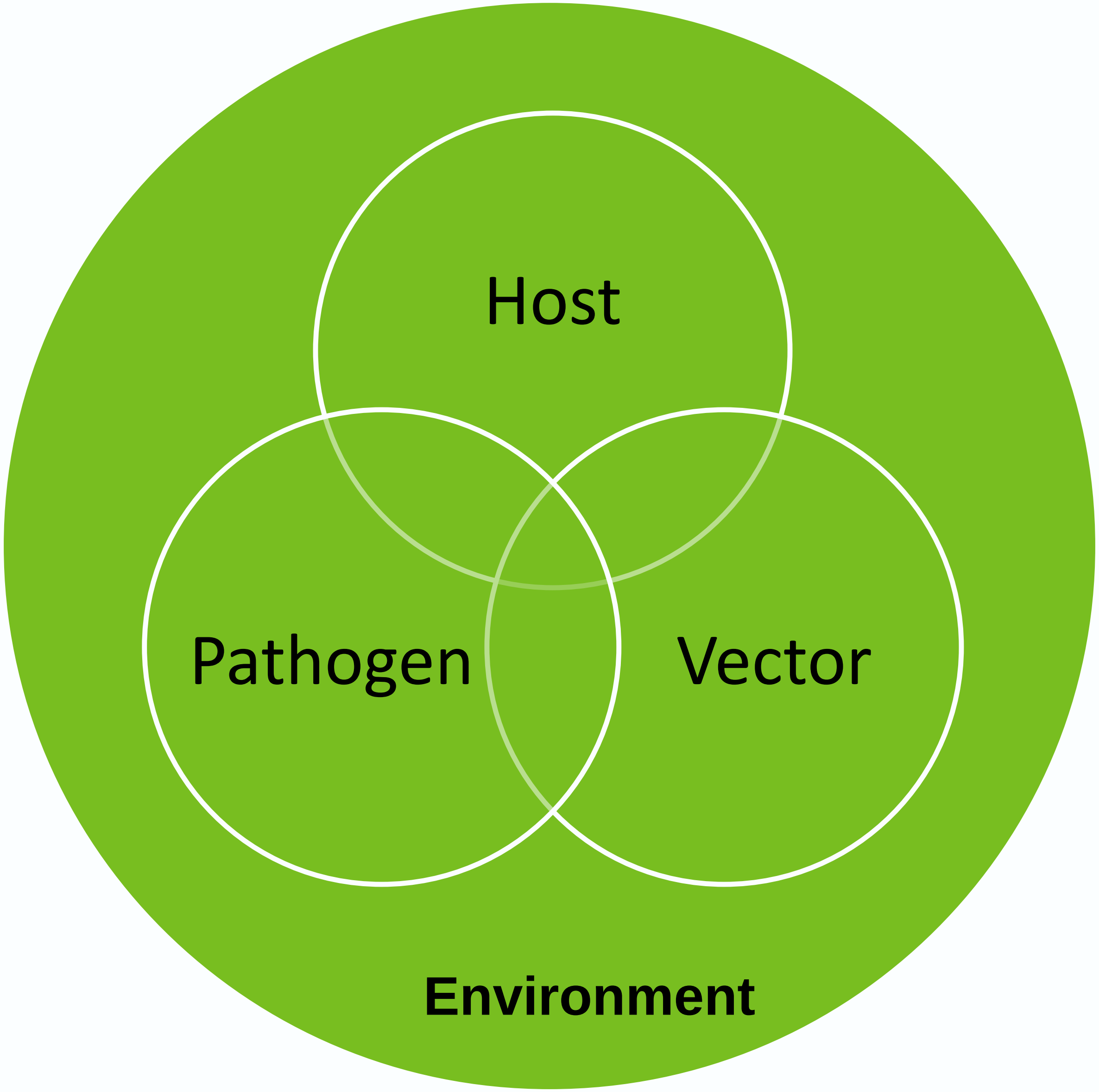
Increased WNV activity has been associated with warm temperatures, mild winters, and drought.

Indications are that WNV transmission will

- expand in the northern latitudes and higher elevations driven by increasing temperature
- decrease in the South if increasing temperatures reduce mosquito survival or limit availability of surface water

Interactions




Host
Pathogen
Vector
Environment

Impacts on Vectors with Changing Climate

- Complex interplay of temperature, precipitation, humidity
- With increased temperature can anticipate:
  - Increase in range, abundance, seasonal activity and length of biting season of vectors
    - *However, temperature may also negatively impact survival in some areas*
  - Increase in biting rates
  - Increase in number of competent species (that is, additional species will become competent)
  - Shorten life cycle (due to shortening of stages of development)
  - Shorten extrinsic virus replication rates (therefore shorten development time of the virus within vectors)
- Changes in precipitation
  - More drought in some areas, higher number of large precipitation events in others
  - Impacts variable - larvae/pupae may be 'washed away' from habitats in heavy rainfall events

Impacts on Vectors with Changing Climate

- Local farm level, environmental factors come into play
  - Likely impacts of temperature, humidity, light intensity, wind speed
  - Activity, biting rates, short and long-distance dispersal
- Impacts on long-distance dispersal
  - Activity at ground level affected by temperature, humidity, rainfall, wind
  - Change in cyclones, monsoonal winds, impact of extreme events?

Impacts on Host of Changing Climate

- Change in livestock distribution, due to changes in water availability, temperature
  - Change in crop availability
- Extended season outside; for example in northern latitudes where animals housed in winter
  - Exposure to vectors for extended season

Other contributing factors in vector dispersal, distribution

- Globalisation, trade
  - Inadvertent movement of vectors, pathogens in cargo
- Land use; agricultural practices (animal, crop)
- Urbanisation
  - Changed human/animal/wildlife vector interface
- Socio-economic
- Changes in surveillance, data collection
  - Species present previously, just not detected?
- Presence of other insect species (competitors)
- Seasonal and photoperiodic variation

An Example – Tick-borne Encephalitis

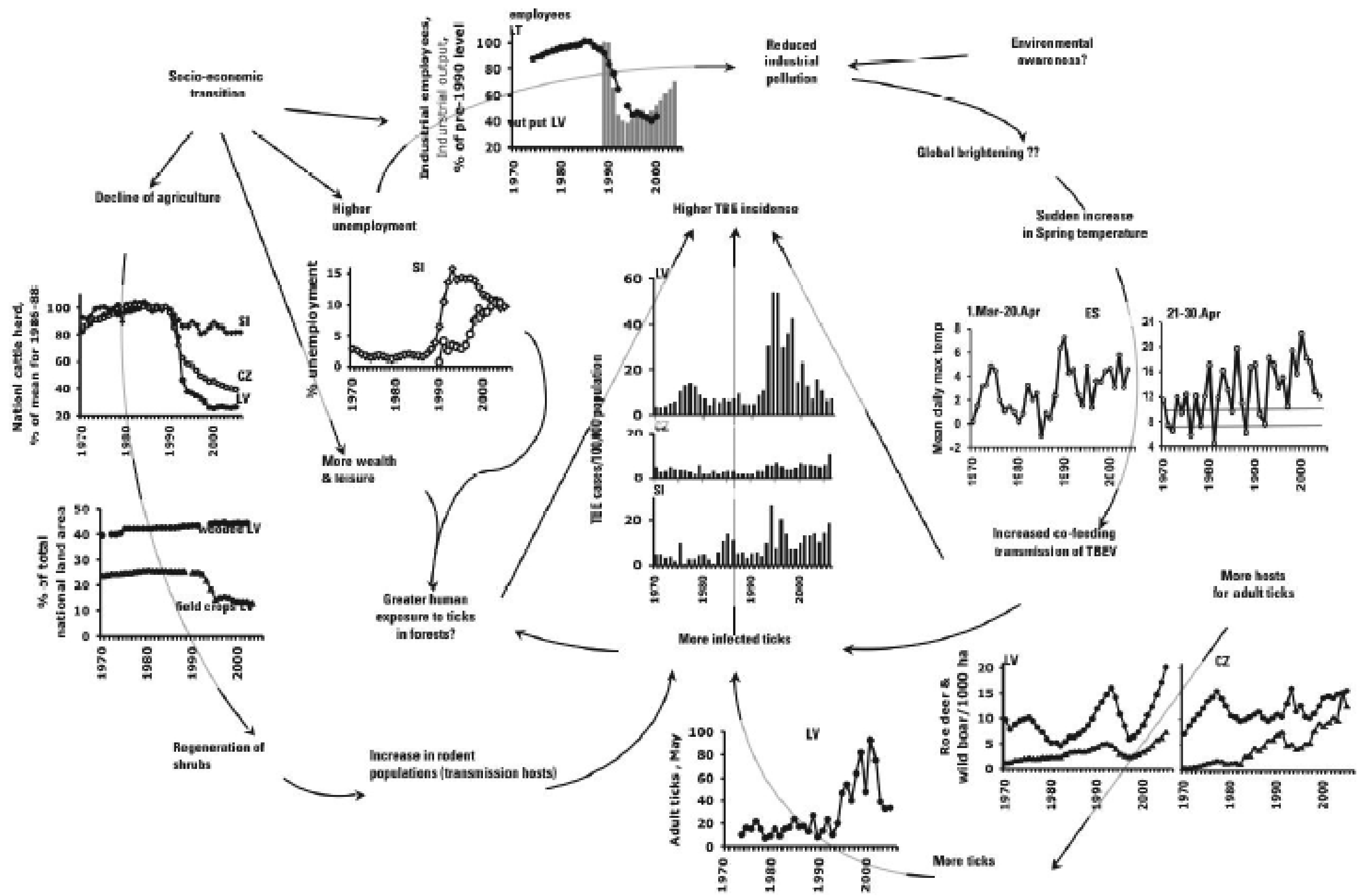


Fig. 5

Hypothetical explanation for the differential upsurge of tick-borne encephalitis in Central and Eastern European countries

Vector Dispersal

- Short distance, directed, intentional (feeding, breeding)
  - *Culicoides* <5km
  - Mosquitoes 50m-48km (average 3-5km)
- **Long distance windborne dispersal**
- Dispersal in cargo/transport

SCIENTIFIC REPORTS

Article | OPEN | Published: 24 October 2017

Direct Evidence of Adult Aedes albopictus Dispersal by Car

Roger Eritja, John R. B. Palmer, David Roiz, Isis Sanpera-Calbet & Frederic Bartumeus

Scientific Reports **7**, Article number: 14399 (2017) | Download Citation

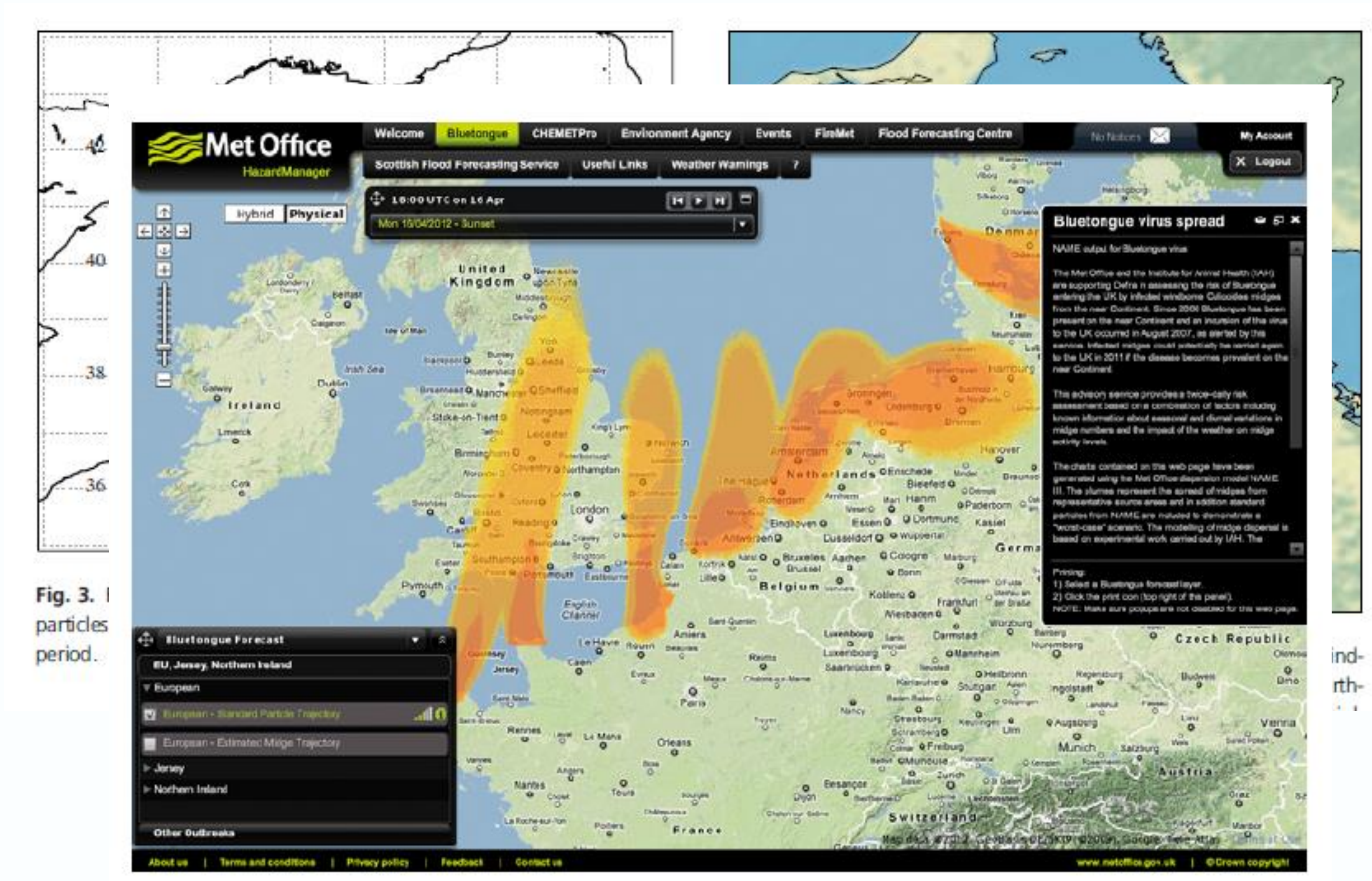
Culicoides

- >1450 species worldwide; present on all continents except Antarctica
- >40 species implicated as vectors of diseases notifiable to the OIE
    - Most notably African Horse Sickness, bluetongue
    - Also vectors of simbu viruses, EHD; nematodes, bacteria, protozoa
- Very small (1-3mm); females are mostly obligate blood-feeders
- Varied habitats (water/moisture a requirement for all life stages)
- Dispersal
    - Short-range <5km
    - Long-range – wind dispersal;
      - in cargo (animals, other items)

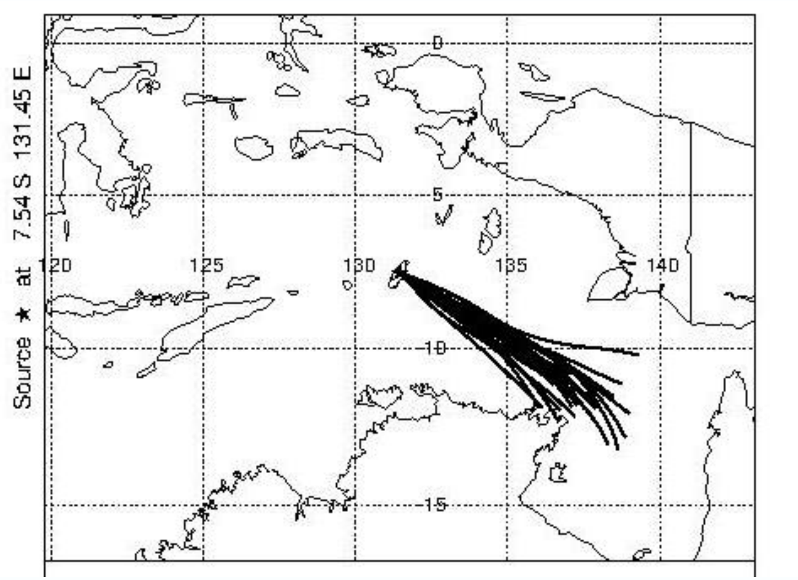
Long Distance Wind-borne Dispersal

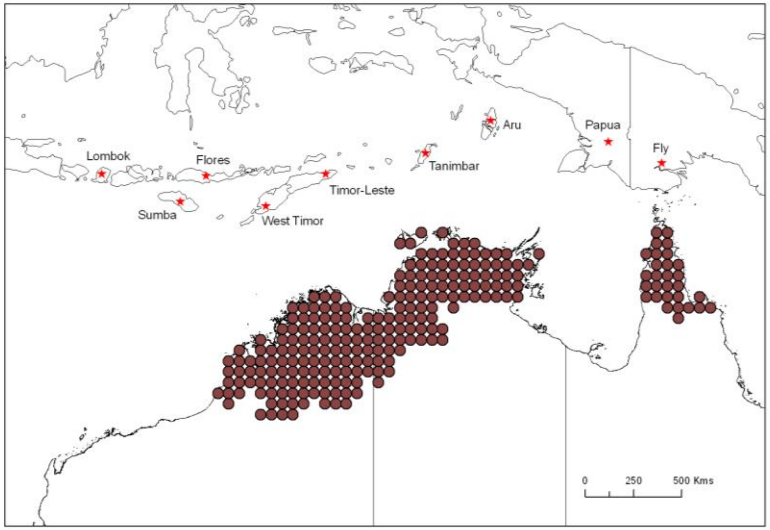
- Outbreaks of bluetongue, African Horse Sickness & other *Culicoides*-borne viruses have been linked to long distance dispersal since 1930s
  - Based on a combination of outbreak information; absence of other plausible means of transmission, suitable meteorological conditions, modelling
- In Australia, novel isolates of bluetongue occasionally detected in northern Australia
- In a number of studies *Culicoides* caught at altitude
  - Above oceans (including 180km from land)
  - At altitude (including >4000m above land)

Paper	Outbreak Location	Source Location	Year	Virus	Model Used	Dataset/s	Assumed or inferred take-off time/temp/height or hPa/ wind speed	Comment
(Sellers, Pedgley et al. 1977)	Spain Cyprus Cape Verde Is	Morocco Turkey Senegal Is	1966 1960 1943	AHS AHS AHS	None	Synoptic weather charts	Any/15-40ºC/ Variable/ Variable	Inferred flight time up to 20 hrs and flight range 40-700km; based on exclusion of all other modes of transmission
Sellers, Pedgley et al. 1978	Portugal	Unknown (Morocco?)	1956	BTV-10	None	Synoptic weather charts	Early morning/18-20ºC/<1500m/5-10m/s	
(Sellers, Gibbs et al. 1979)	Cyprus	Syria, Turkey?	1977	BTV-4	None	Synoptic weather charts	NA/20-35ºC/500-1500m/2.7-5.5m/s	Distances 100-200km; wind dispersal considered the most likely mode transmission
(Sellers and Pedgley 1985)	W.Turkey	Cyprus?	1977	BTV-4	None	Synoptic weather charts	Dusk/~20ºC/~500m/11 m/s	Other modes transmission not ruled out but route mainly over sea and no evidence of infection in between
(Murray 1987)	Australia	Australia	1983	Akabane	None	Synoptic weather charts	Evening/23-28ºC/NA/NA	*C. brevitarsis* unable to replicate in outbreak areas (therefore spread disease without replication); distance 130-200km over land
(Sellers and Maarouf 1989)	Florida, USA	Cuba?	1982	BTV-2	None	Surface and 850mb Northern Hemisphere weather maps	Evening/15-17ºC/100-1500m/7m/s	Distance 500km covered over 20hrs; considered the most likely mode of transmission
(Sellers and Maarouf 1991)	British Columbia, Canada	USA?	1987	BTV-11 EHD-2	None	Synoptic weather charts	Variable/min 10ºC/<1500m/3-5m/s	Distances up to 130km over land
(Murray and Kirkland 1995)	Australia	Australia	1989	BTV Douglas Daly	None	Synoptic weather charts	NA	Distance 150-200km; used sentinel herds and extension of Culiocides into unsuitable areas for survival
(Braverman and Chechik 1996)	Israel	Iraq?	1964, 1966, 1988	BTV	None	Meteorological data	NA/>15ºC/1000 or 1500m/<10m/s	Evidence of infection in proposed source region not available
(Alba, Casal et al. 2004)	Balearic Is	Sardinia?	2000	BTV-2	None	Meteorological data	NA	Based on exclusion of all other modes of transmission and support of meteorological evidence



Burgin et al 2012

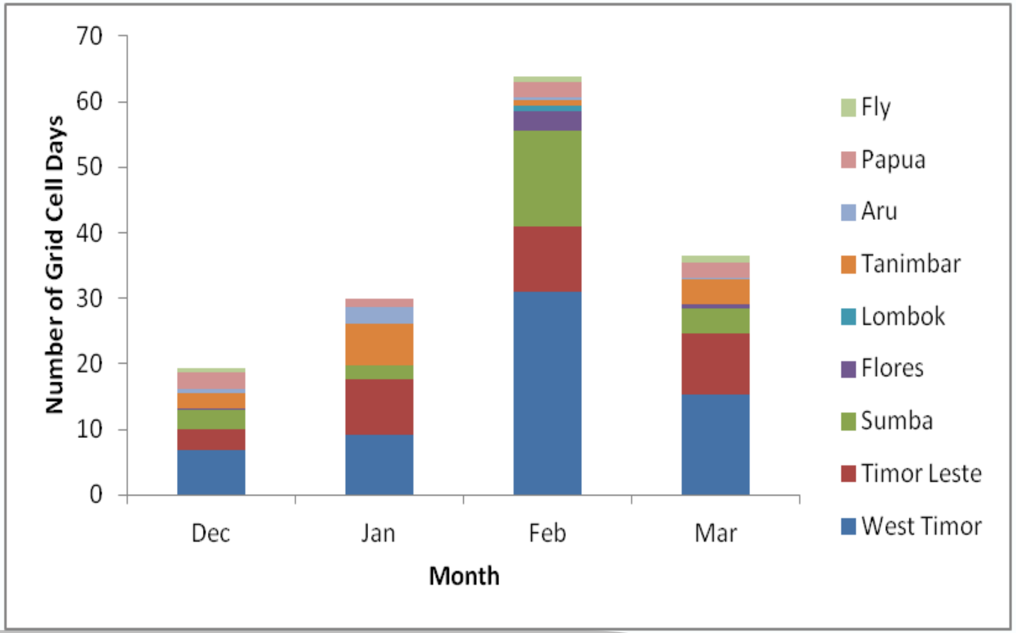


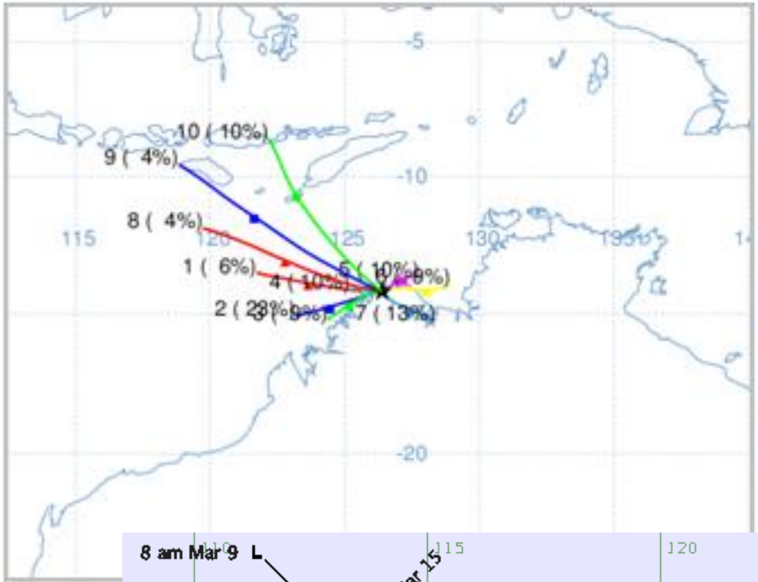


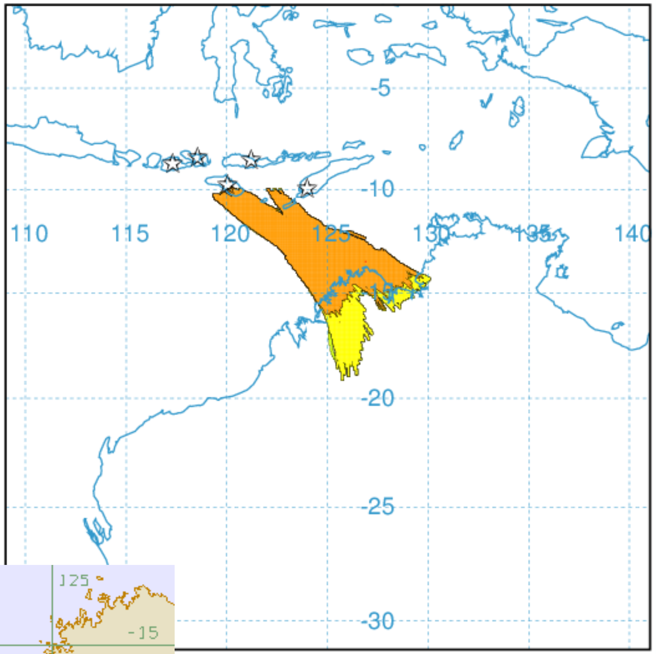
Showed <u>patterns</u> of dispersal.

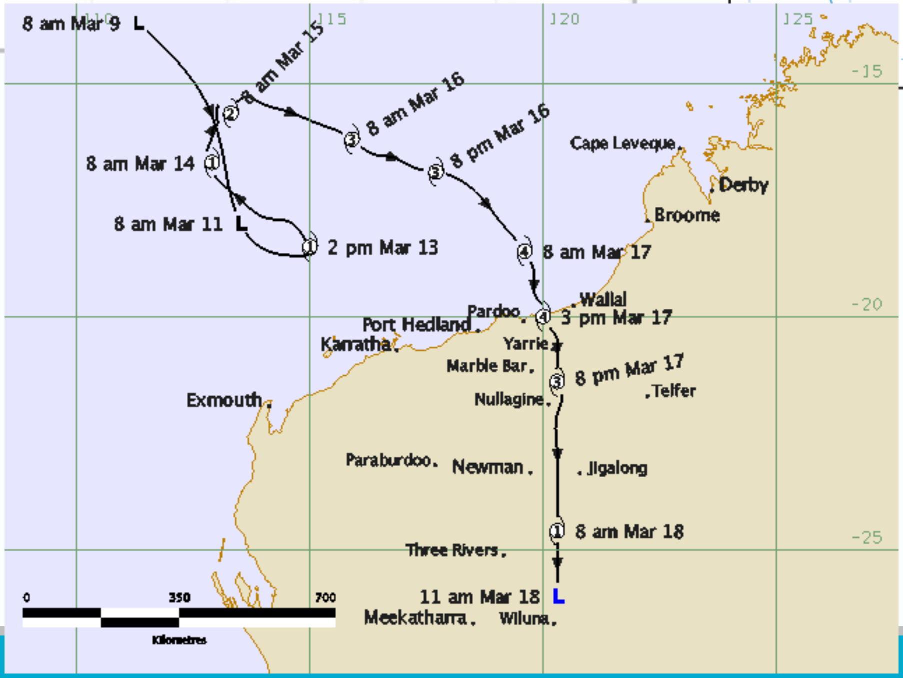
Distances of >1000km feasible in 20 hour dispersal event

- Likelihood of survival?
- Infection status?









No direct correlation with cyclones; however some dispersal events (with exotic Culicoides detection) occurred around time of cyclone – impact of change in cyclone numbers, severity?

Source Population

- Ruminant population at source
- Culicoides population at source
- Bluetongue in source population

Dispersal Event

- Dispersal event
- Survival of Culicoides during dispersal
- Survival of Culicoides on arrival

Arrival & Infection

- Population of ruminants on arrival
- Culicoides bite/s ruminant/s
- Infection (with subsequent viraemia) of ruminant
- Subsequent bite by Culicoides

Disease Spread & Detection

- Amplification in ruminant population
- Detection in sentinel herd and/or in clinically unwell animal

Bluetongue – Geographical Expansion in Europe
Example of complexity of factors

- Initial introduction
  - Exact source and route unknown
  - Likely illegal movement animal/materials (vaccine implicated)
- *C. imicola*
  - Already present in Europe, and vector of many other serotypes, but not present in all affected areas
  - Increased distribution, or detection in areas not previously surveyed?
  - Contribution of climate change
- Palearctic species (eg. *C. dewulfi, obsoletus*)
  - Present in northern Europe; not previously recognised as vectors
  - Within infected zone – cases presented in warmer areas
- Long-distance wind dispersal
  - Important for 'within outbreak' dispersal to some areas

Gaps and Challenges

- Evidence of short-term or regional impacts of ‘emerging’ diseases (many of which may be due to climate change)
  - Few examples of longer term/global impacts
- In some countries/regions – poor understanding of vector presence, competence
  - No ‘baseline’ to measure change
- Absence of high quality data
  - Temporal and spatial resolution
  - Multi-disciplinary (human, animal, entomological, social)
  - Basic biological information missing regarding interaction with ecosystem and response to environmental changes
  - Data harmonisation
- Limited cost-benefit analysis of interventions

"Changes in the global climate are expected to have a profound impact on arthropod vectors of livestock diseases, altering current distribution patterns and modifying their ability to transmit pathogens."

(Elbers et al 2015)

HOWEVER

Interplay between different climatic factors (particularly temperature, humidity, precipitation); their impacts at both a local and a global scale; on individual species and taking into account the complexity of abiotic factors are not well understood.

Good surveillance systems and an understanding of vector biology and vector/host/pathogen interactions is essential.

Thank you

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