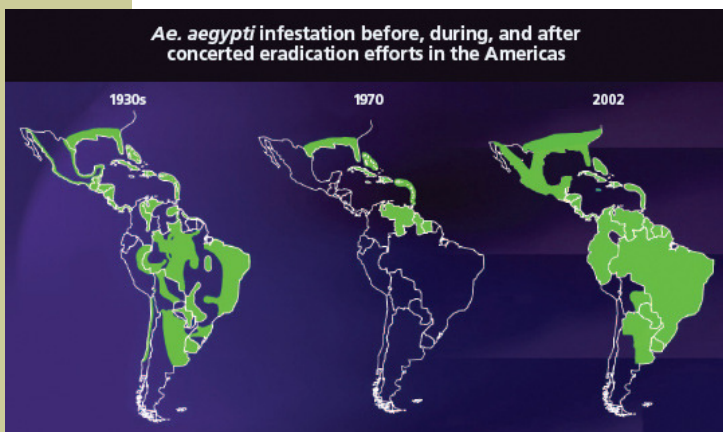
Bachelor thesis

Effects of climate change on the introduction of new viral infections in endemic regions



Kimberley G. D. Pawironadi
Supervisor: Hubert G. M. Niesters

Rijksuniversiteit Groningen

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Picture sources:

1 Arias JR. 2002. Dengue: how are we doing? Washington, DC: Pan American Health Organization

2 The sun powers the earth's weather. Planet Earth: Pole to pole. 2009. Available at: http://www.powermediaplus.com/images/planet-earth-art.jpg. Date retrieved: 24 March 2009

Summary

Climate change is often associated with disastrous events and awful consequences for humans and animals, such as hotter summers, rising sea levels, and even health. Human activities including the burning of fossil fuels and deforestation have led to climate change. In the past decades many events have been occurring as a direct consequence of climate change; warmer winters, hotter summers and heat waves, drought, more hurricanes and precipitation. But also human and animal health has been affected by climate change.

This review describes how West Nile Virus, Dengue Virus, and Bluetongue Virus have been able to survive in countries or regions where they have never been seen before. Due to warming temperatures many disease carrying insects are able to spread to other regions and countries where they have never been before. But also other factors of climate change such as increased precipitation and rising sea levels influence the spread of these insects and the diseases they carry.

Nobody really knows what climate change is capable of doing, and what other consequences it might cause in the future if no action is taken. For this reason, it is hard for scientist to elucidate where viral diseases carried by vectors will spread to. Therefore, more research needs to be done on both climate change and disease transmission by vectors. Meanwhile, humans need to figure out another way to protect themselves from such diseases.

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Introduction

Climate change and global warming are two terms that have been used frequently throughout the past 30 years. Global warming is an increase in the Earth's atmospheric temperature that causes corresponding changes in climate [Dictionary.com]. These changes include rising temperatures of the Earth's surface, drought, warmer winters, and also extreme events such as heat waves, severe storms and flooding [Epstein PR 2001]. Climate change has many unpleasant consequences for humans and animals alike. Too much drought causes less water to be available for crop to grow, while too much water can cause erosion eliminating the nutrients needed for plant-growth [Long et al 2006; Moffat 1992]. This decrease in crop yield affects the agricultural sector negatively. Moreover, food supply might become insufficient to feed world population. Just like hurricane Katrina in 2005 and other past disasters, future severe storms and hurricanes will cause many casualties and huge capital losses. Aside from affecting climate itself, the health sector is also threatened by the consequences of climate change in many ways.

In the past decade, humans alone have experienced at least ten different viral disease outbreaks including West Nile Disease, Rift Valley Fever and Dengue [who.int, Disease outbreaks by year 2009]. Aside from Bluetongue, animals have also experienced West Nile and Rift Valley Fever [Zampaglione]. Remarkably, many of these diseases have been able to spread themselves quickly from one region to another. Even more puzzling is that viruses which cause these diseases reached countries in temperate zones, where the cold environment usually makes it difficult for them and their vectors to survive and replicate [Epstein 2001; Shope 1991]. Many consequences of climate change contribute to increasing prevalence of various diseases and their distribution around the world.

This review focuses on factors of climate change that are able to cause introduction of viral infections – in humans and animals – in new regions. Therefore, the development of climate change will be explained first. West Nile Virus (WNV), Dengue Virus (DENV), and Bluetongue Virus (BTV) illustrate how climate change has contributed to their introduction in new countries. Furthermore, it is illustrated how future epidemics can be predicted and people can reduce the prevalence of these viral infectious diseases in both humans and animals.

Climate Change

Towards the end of March 2009, 1500 penguins from Antarctica stranded on the beaches of Chile, 2000 km away from their normal habitat [Brisbanetimes.com]. Was this due to global warming? *Climate change is a periodic modification of Earth's climate brought about as a result of changes in the atmosphere as well as interactions between the atmosphere and various other geologic, chemical, biological, and geographic factors within the Earth system* [Encyclopedia Brittanica 2008]. These changes are especially caused by human activities, such as the burning of fossil fuels and deforestation. By burning fossil fuels such as coal, oil, and natural gas, greenhouse gases are released into the atmosphere. These gases include carbon dioxide, methane, nitrous oxide and hydrocarbons [Epstein 2001; Khasnis et al 2005; Sutherst 2004]. The purpose of these gases is to keep the Earth warm. But too much accumulation of greenhouse gases in the Earth's atmosphere causes temperatures to rise to uncommon high temperatures (Figure 1). Soil and trees are able to take up these gases to prevent the Earth from overheating. This way, temperatures can be maintained within a certain range. Unfortunately, deforestation takes away this mechanism and therefore causes temperatures to keep rising [Khasnis et al 2005].

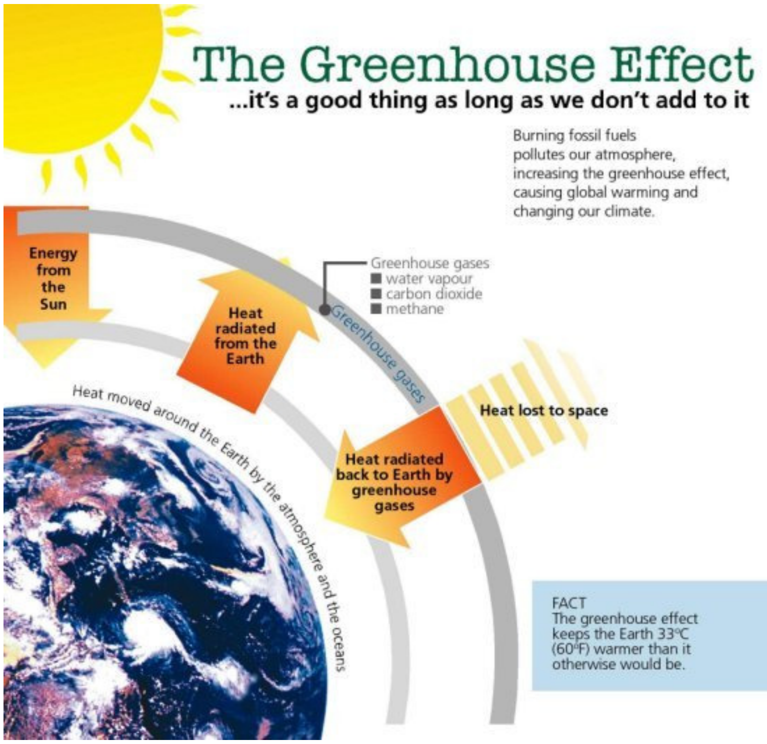

Figure 1 The Greenhouse Effect. The Earth receives heat waves from the sun. Some of this heat is radiated from the Earth back into space. Greenhouse gases in the atmosphere prevent heat from being radiated into space, and keep the heat within the Earth's atmosphere.

In the last century, people and animals have experienced many dreadful events as results of climate change. To make matters worse; the effects of climate change are still increasing in frequency as well as intensity. The most important element contributing to climate change has to be temperature rises of the Earth's surfaces, which are going at a remarkably fast rate. From 1901 to 2000 global mean annual land surface temperatures have increased with approximately 0.8ºC [ncdc.noaa.gov] (Figure 2), and are expected to rise 1.4 to 5.8ºC by the year 2100 if no action is taken [Khasnis et al 2005]. These rising temperatures have various effects on the Earth's climates.

Many temperate countries are experiencing shorter, less severe, and warmer winters [Sutherst 2004], while summers get hotter and unbearable for some people. The European heat wave of 2003 was the most intense heat wave of the century killing around 35 000 people [Bhattacharya S, 2003]. The 2006 European heat wave was also one of the hottest of the past century, and reached an abnormally high temperature of 35ºC in the Netherlands [Nellestijn J, 2006].

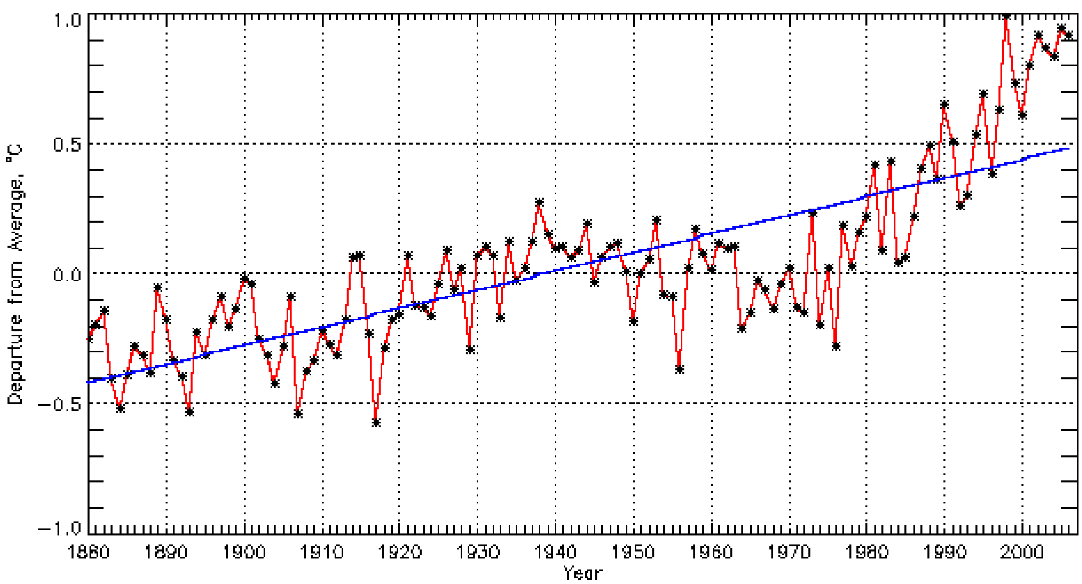

Figure 2 Annual temperature anomalies from 1880-2000. Peaks represent highest annual temperatures (during summer) and dips represent lowest annual temperatures (during winter). Both dips and peaks have risen since 1880, implying hotter summers and warmer winters. An average increase of 0.8ºC is observed.

The tropics also suffered from extreme weather events. Andrew, Gordon and Katrina were three of the strongest, most disastrous hurricanes of the last twenty years [nhc.noaa.gov]. In his previous study *Emanuel* concluded that hurricanes increased in destructiveness over the past 30 years, and are likely to keep increasing as sea temperatures keep rising [Emanuel 2005]. The intensity of a tropical storm is influenced by sea temperatures, and that high sea temperatures result in more destructive hurricanes. Even though sea temperatures are increasing on all parts of the globe, hurricane intensities are not. Thus, sea temperature is not the only factor that influences the potential intensity of tropical storms [Vecchi et al 2007]. Yet, some scientists doubt that hurricanes will keep getting more destructive [Trenberth 2007; Landsea 2005].

Higher temperatures also affect the hydrological cycle or water cycle on earth (Figure 3) [Epstein et al 1998; Epstein 2007; Khasnis et al 2005]. The elevated temperatures cause faster evaporation of water, and condensation of vapor into clouds which precipitate when saturated. The IPCC stated that precipitation has increased throughout the 20th century due to anthropogenic activities, and is likely to increase even more in the future [International Panel for Climate Change].

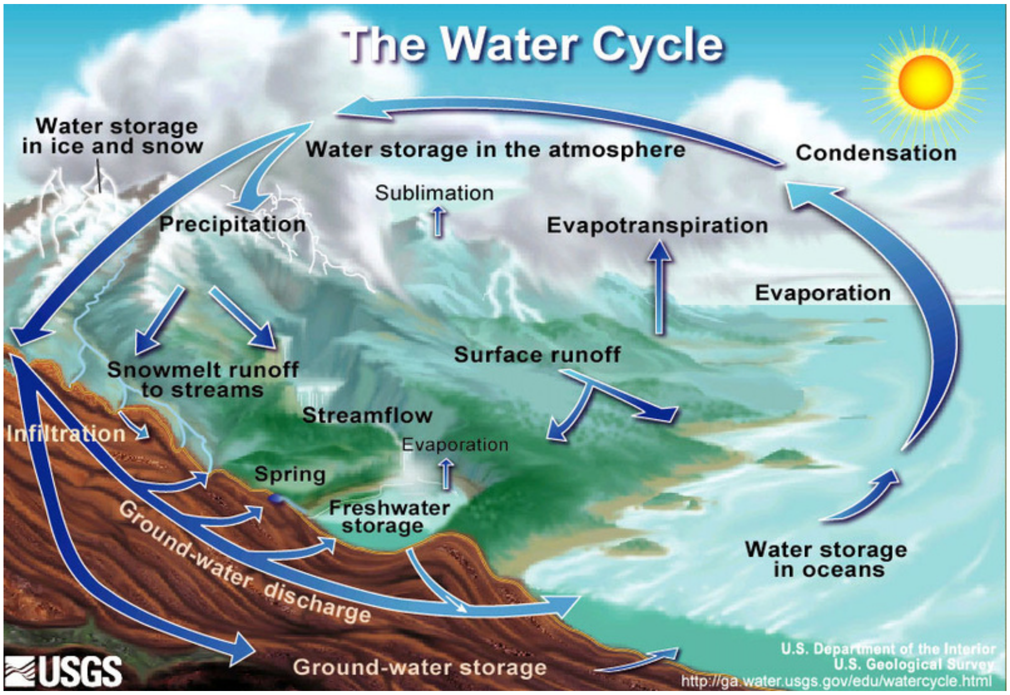

Figure 3 The Water Cycle driven by temperature changes. High temperatures cause ice to melt and water to evaporate, while cool temperatures cause condensation and freezing.

Introduction of virus infections in new regions

Many countries around the world have experienced multiple viral disease outbreaks. Just last year, in 2008, the World Health Organization (WHO) reported a total of nine different disease outbreaks occurring twenty-three times in twenty different countries (Table 1). Outbreaks affected diverse countries including Brazil, Paraguay, South Africa, Congo, Egypt, Madagascar, Pakistan, Vietnam, China and Indonesia. It is noticeable that all outbreaks occurred in warm and dry regions. This suggests a relation between the environment and the occurrence of viral infectious diseases. Additionally, in October 2008 a new virus of the *Arenaviridae* family caused hemorrhagic fever in inhabitants of South Africa and Zambia. Further research is still in process to find out more about this virus and its mode of transmission [who.int, Dengue and Dengue Hemorrhagic Fever].

Table 1 **Disease Outbreaks in 2008**

Disease	Countries
Avian Influenza	Egypt, Vietnam, China, Bangladesh, Indonesia, Pakistan
Rift Valley Fever	Sudan, Madagascar
Yellow Fever	Brazil, Paraguay, Liberia, Central Africa, Cote D'Ivoire, Guinea, Burkina Faso, Sierra Leone
Dengue Fever	Brazil
Severe Acute Watery Diarrhea	Vietnam
Enterovirus	China
Poliomyelitis	Nigeria
Ebola	Congo
Unknown New Virus	South Africa and Zambia

Although most disease outbreaks of 2008 occurred in warmer climates, this does not imply that temperate climates do not deal with such diseases. In fact, outbreaks that occurred in temperate regions received more attention compared to those in the tropics. West Nile Virus was introduced in 1999 in the United States, and since then it has been spreading to all corners of the country [Zampaglione]. Dengue is the most widespread disease that primarily occurs in tropical climates. But, many scientists have reason to think that the region of the distribution of Dengue is expanding in altitude and longitudinal and latitudinal direction [Epstein et al 1998; Epstein 2001; Reiter P 2001]. The bluetongue virus outbreak of 2006 in Western European countries was associated with enormous economical losses. Not only was there a big loss in cattle products, but huge expenses were also made with surveillance and prevention programs [Wilson et al 2008].

Many studies have been designed to elucidate the relation between climate change and the prevalence of infectious diseases. Some have studied a broad range of infectious diseases, while others only looked at vector-borne or mosquito-borne diseases. Most studies were based on meteorological and historical data. Other studies have shown that besides climatic effects, direct anthropogenic influences i.e. trade and travel, deforestation, urbanization, irrigation and agriculture, should also be accounted for predicting future distribution of viral infectious diseases [Sutherst 2004].

West Nile Disease

West Nile Virus was isolated for the first time, in 1937, from the blood of a febrile woman in Uganda [Hubalek et al 1999; Smith 2007; Strauss 2007]. It was not until 1953 that the ecology of WNV – the mode of WNV transmission – was discovered [Zampaglione]. A few years later (in 1962) following the discovery of the WNV ecology, the disease was also reported in horses in France [Murgue et al 2001]. The West Nile outbreak of 1999 in the United States is very important because it occurred in a region where climate would usually be unsuitable for transmission of the disease. Since then, the disease spread itself to all parts of the US, Canada, Mexico and even South-America [Gould et al 2009]. Each year thousands of infections and hundreds of fatalities are reported in the US [cdc.gov].

West Nile is a disease that affects a broad range of species, especially humans, equines, and most bird species [Gould et al 2009; Hubalek et al 1999; Murgue et al 2001; Smith 2007]. WNV can cause different clinical symptoms in humans. Approximately 80% of humans do not develop symptoms, while 20% experiences a feverish, influenza-like illness. A very small group of people develop a much severe form of West Nile which is characterized by acute aseptic meningitis or encephalitis [Hubalek et al 1999; Smith 2007; Strauss et al 2007]. In horses, the neurological disease may include high fever, muscle twitching, partial paralysis, and grinding of teeth [Murgue et al 2001]. Although birds form a large group that can be infected with WNV, most species are resistant to the disease and, therefore, do not develop any symptoms. However, there are exceptions where some infected birds develop encephalitis or die from the disease [Hubalek et al 1999].

WNV is a member of the genus *Flavivirus*, in the family *Flaviviridae*. There are about 53 species of flaviviruses currently recognized, including dengue virus, tick-borne encephalitis virus, yellow fever virus, and other viruses which may also cause encephalitis [Gould EA et al 2009; Kuno et al 1998; Strauss et al 2007]. Phylogenetic studies identified two lineages in WNV. Lineage 1 viruses contain both virulent and attenuated strains and are responsible for West Nile disease. This lineage is present in North-America, Europe, the Middle East, India, Australia, and parts of Africa. Lineage 2 viruses are only present in sylvatic African environments and are mostly maintained in an enzootic cycle, implying that these viruses are rarely associated with human epidemic outbreaks [Gould EA et al 2009; Smith 2007; Strauss et al 2007].

WNV is an arbovirus transmitted by a wide variety of mosquitoes, principally by those of the genus *Culex* and occasionally by *Aedes* and other mosquitoes [Hubalek et al 1999; Strauss et al 2007]. All arboviruses are transmitted in a similar way. Male and female mosquitoes feed on nectar, but only females are capable of taking blood. When a competent female mosquito takes its meal from an infected bird, it should ingest sufficient amounts of virus in the blood in order to produce high titers of WNV. When ingested, the virus subsequently replicates in the mosquito's midgut epithelium and afterwards spreads to the salivary glands. WNV can be transmitted to another bird, human or mammal when the female mosquito takes a new meal and injects the virus into the new host [Purse et al 2005; Ramos-Castaneda et al 2008]. The virus can also be transmitted orally to other mosquitoes [Pherez FM 2007]. Birds are the primary reservoir for WNV because only in birds does the virus produce high enough viremia titers to infect mosquitoes [Hubalek et al 1999; Strauss et al 2007;]. Humans and other mammals are dead-end hosts for WNV, implying that further infections to other humans or mammals do not take place. Mosquitoes are able to spread WNV by two mechanisms of vertical transmission (VT) [Pherez FM 2007]. Transovarial transmission is the transfer of pathogens to succeeding generations through invasion of the ovary and infection of the eggs [Strauss et al 2007; Mosby's medical dictionary]. The other mechanism of VT comprises the infection of eggs from female arthropods after oviposition. Both forms of VT lead to venereal transmission from male to female mosquitoes [Pherez FM 2007]. All transmission pathways are summarized in figure 4.

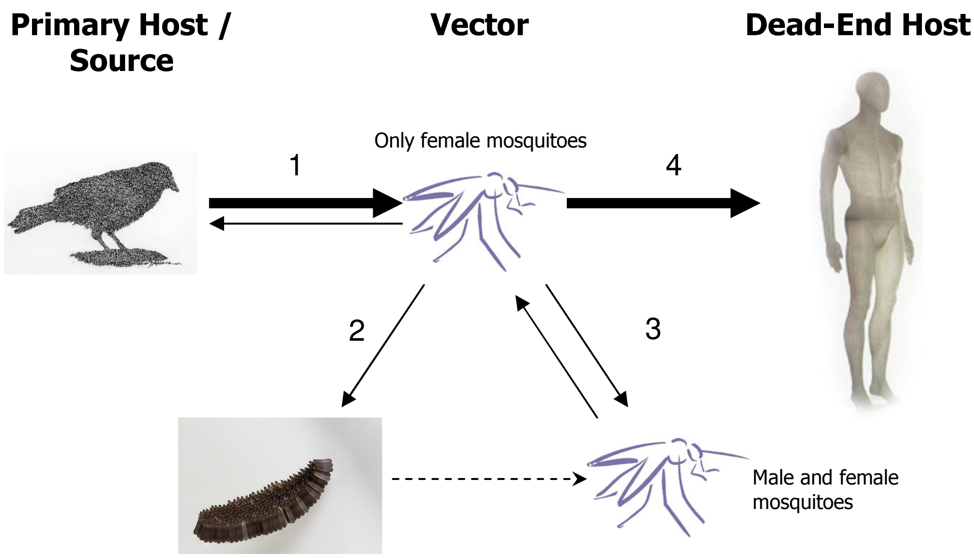

Figure 4 Transmission of West Nile Virus 1) Infection of mosquito or bird during meal-taking of mosquito 2) Transovarial transmission 3) Transvenereal Transmission 4) Transmission to dead-end host

Although it is appealing to understand how West Nile was introduced in the US in 1999, it might be of more importance to understand why it was able to survive and spread itself all over the country. Mosquitoes are very susceptible to their surroundings and climate changes. Temperature which has a prominent role in influencing climate change also influences many aspects of viral transmission by mosquitoes. Mosquitoes, including *Culex* and *Aedes*, are usually located in warm climates with temperature ranges of 16ºC to 40ºC [Epstein et al 1998; Patz et al 1998]. Mosquitoes are not able to survive well in environments with temperatures outside of this range. Studies have shown that *Aedes aegypti* – which also transmit WNV – rapidly die at freezing temperatures and their larvae at 9ºC [Epstein 2001; Patz et al 1998; Shope 1991]. But, mosquitoes that find themselves in environments with optimal temperatures ranging from 25ºC to 30ºC [Straetemans 2008] show increased activity, and increased frequency of meal-taking [Epstein et al 1998; Epstein 2001; Sutherst 2004]. Previous studies showed that development of larvae and maturation of mosquitoes is also faster in optimal temperatures [Epstein et al 1998; Epstein 2001; Shope 1991; Straetemans 2008]. The extrinsic incubation period (EIP) is the period between feeding on infected blood and the appearance of virus in the saliva of the arthropod vector which is also temperature-dependent. Temperature elevations result in shorter incubation periods, enabling mosquito-borne diseases to spread faster in a certain population [Gould et al 2009; Shope R 1991; Wang et al 2005]. As temperatures keep rising, winters get warmer making it easier for vectors of West Nile to survive in regions where they have never been before. Previous studies also showed that certain mosquito species including *Culex pipiens* and *Aedes albopictus*, are able to survive winters with temperatures above 0ºC [Reiter 2001; Straetemans 2008]. In addition, several studies demonstrated that mosquitoes have been observed at higher altitudes in mountain regions where they were not seen before [Epstein et al 1998; Epstein 2001; Patz et al 1998]. Furthermore, *Epstein et al 1998* imply that a changed mosquito distribution corresponds to a change in latitudinal distribution. Thus, if mosquitoes are seen at higher elevations, one can expect that they are also spreading to colder regions of the northern and southern hemisphere.

In theory, mosquitoes are restricted to regions with temperatures higher than 10ºC [Epstein 2001]. Throughout most of the year New York temperatures are normally low and unfavorable for mosquitoes to survive. But, in the summer of 1999, temperatures were high enough for mosquitoes to survive and reproduce [climate-charts.com; Gould et al 2009; nrcc.cornell.edu].

In terms of medicine, horse vaccines have been developed and are applied [Strauss et al, 2007], but human vaccines are still not available. Humans thus need other ways to protect themselves against West Nile. Citizens are advised to avoid mosquito bites by using door and window screens. People are also advised to wear light-colored clothes and to use insect repellents. In addition, citizens should also eliminate mosquito breeding sites by emptying standing water from objects in the yard, cleaning rain gutters, chlorinating swimming pools, and removing debris - such as old tires - that can hold rainwater [gnb.ca; westnilevirusfacts.org].

Dengue Fever

Dengue might be an ancient infectious disease in humans. It dates as long ago as 902 A.D. during the Chin Dynasty. The disease was called water poison and was associated with flying insects. The first reported epidemics of Dengue Fever (DF) occurred in 1779-1780 in three different continents; Asia, Africa, and North-America [Gubler 2008]. It was around this period that Benjamin Rush – a Founding Father of the US – described a disease in Philadelphia which he called break-bone fever, now known as dengue [Lai et al 2007].

Dengue virus and WNV share many similarities. Both viruses belong to the genus *Flavivirus* of the family *Flaviviridae*. Most flaviviruses are arthropod-borne which entails that they are transmitted by mosquitoes. This implies that DENV and WNV use the same transmission mechanisms to infect host after host by. DENV is primarily carried by *Aedes aegypti* and occasionally by *Aedes albopictus* and other mosquitoes [Gubler DJ, 2008; Lai et al, 2007]. Unlike WNV, DENV does not affect a broad range of species but is mostly restricted to humans and mosquitoes.

The incidence of Dengue has grown dramatically around the world in recent decades. The WHO estimates that some 2.5 billion people are now at risk for DENV infections, and that there may be 50 million dengue infections worldwide every year. Most of these infections occur in tropical and sub-tropical climates, where dengue is endemic [who.int, Dengue and Dengue Hemorrhagic Fever]. The resurgence of dengue in the tropics was primarily a consequence of lack of vector control, and demographic and societal changes over the past sixty years. Population growth increased immensely during the last few decades, and had many unanticipated consequences such as increased urbanization and deterioration in water, sewer and waste management systems. Urbanizations are known to be abundant in shallow water which is an ideal breeding site for mosquitoes [Gubler 1998]. It is hypothesized that urbanization and, thus, population density will increase due to climate change. As implied before, increased urbanization is associated with an increase of disease-prevalence [Khasnis et al 2005; Sutherst RW].

The warming of the Earth's surfaces causes ice in mountain regions, and on the North and South poles to melt [Epstein 2001]. Subsequently, sea level will rise and humans will have to migrate to higher altitudes. Also, land available to be inhabited diminishes as sea levels rise. This causes people to live more concentrated, therefore increasing population density. Moreover, the Earth is inhabited by approximately 7 billion humans and is expected to increase with another 5 billion by 2030 [Sutherst 2004; worldometers.info]. This additionally leads to increased population density. Finally, outer urban development in or near forests will increase as a result of cities becoming too crowded. This allows the contact between humans and vectors to increase [Sutherst 2004].

Climate change will also affect the prevalence of arthropod-borne diseases more directly. In the West Nile case, much attention was already drawn on the influences of temperature elevations. But, there are many other factors of climate change that could be responsible for the increased incidence of such disease. Besides its temperature-raising effects, CO_2 has a more direct influence on the prevalence of mosquito-borne diseases. Higher concentrations of CO_2 makes plants reduce their water through transpiration loss and produce more foliage. Increased density of plant foliage will provide more favorable microclimates for insect vectors [Sutherst 2004]. Additionally, reduced transpiration of plants results in increased soil moisture. When soils get saturated, water reservoirs suitable for breeding mosquitoes are produced [Khasnis et al 2007; Sutherst 2004]. Additionally, breeding sites can be increased as a consequence of increased rainfall in the future [Epstein 2001; Sutherst 2004].

Back in the days when DF was not such a wide-spread disease, it was mostly considered a mild, nonfatal disease [Lai et al 2007]. Aside from the growing incidences, new and more severe forms of dengue have emerged, including dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS). Four DENV serotypes are recognized; DEN-1, DEN-2, DEN-3, and DEN-4 [Gubler, 1998;Lai et al, 2007; Strauss et al, 2007]. Infection with dengue can be subclinical which is usually characterized by a severe headache, muscle pain (myalgia), bone pain, fever, rash, and weakening of the body. This is also known as classic dengue fever which may result in severe forms of dengue associated with a significant mortality rate. Dengue hemorrhagic fever (DHF) and dengue shock syndrome (DSS) is generally observed in people who have already been infected with DENV. After a first infection with DENV of a certain serotype, the body produces antibodies against this serotype. A second infection with the same DENV serotype – a homologous infection – does not cause an immune reaction, but is neutralized instead. However, the individual becomes fully susceptible to infection with other serotypes. When one is infected with a heterologous DENV serotype, formerly produced antibodies against the first DENV serotype sub-neutralizes the infection by performing a cross-reaction with the new DENV serotype. Controversially, these sub-neutralizing concentrations enhance dengue infection causing a severe immune reaction that may lead to DHF or DSS. The severity of DHF or DSS depends on the immune reaction of the individual and is possibly controlled genetically [Halstead 1988; Lai et al 2007].

2100 years after the first description of a disease presumed to be dengue, no specific treatment has been developed yet. Currently, attempts are made at discovering an effective drug for dengue. Scientists are now experimenting with inactivated viruses and live-attenuated virus vaccines [Lai et al 2007], but more research has to be done before they can be applied. As in the case of West Nile, many organizations have set up guidelines to prevent mosquito bites.

Bluetongue

Bluetongue is a non-contagious viral disease affecting domestic and wild ruminants, and is transmitted by biting midges [Mellor et al 2008; Wilson et al 2007]. Even though it does not cause disease in humans, it does affect them financially. Export restrictions are put on diseased cattle which results in a smaller distribution and income. Subclinical infections including loss of condition, reduced milk yield, infertility and abortion are also associated with significant costs. Furthermore, surveillance, treatment and vaccination all contribute to more costs for the disease [Wilson et al 2007].

Bluetongue is widely distributed in a broad band across all continents of the globe stretching from 35ºS to 40ºN, although in certain areas it may extend up to 50ºN [Mellor et al 2008; Strauss et al, 2007] (Figure 3). In Europe bluetongue was pretty much restricted to the more Southern countries such as Cyprus, Portugal, Spain and a few Greek Islands [Mellor et al 2008]. This distribution pattern changed in the years following 1998, when bluetongue was entering the more Northern countries of Europe. In 2006, Dutch authorities reported the first ever case on bluetongue in Northern Europe [Wilson et al 2007].

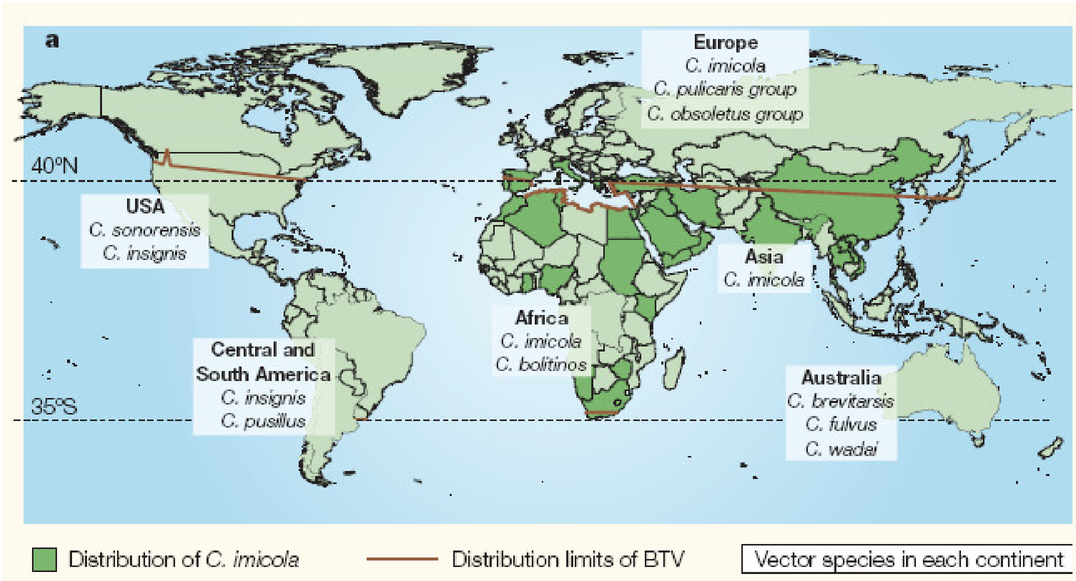

Figure 3. **Bluetongue disease distribution** *(Purse et al, 2006)*

Bluetongue virus is a virus of the genus *Orbivirus* of the family *Reoviridae* and contains 24 serotypes [Mellor et al 2008; Strauss et al 2007; Wilson et al 2007]. Different orbiviruses infect a wide range of higher vertebrates including ruminants, horses, rodents, bats, birds, and primates including humans. So far, no BTV infection has been observed in humans. *Orbiviruses* are arboviruses transmitted by biting flies, mosquitoes, or ticks, and are able to replicate in the vector as well as in the host [Strauss et al 2007]. *Culicoides imicola* are the primary vectors that transmit BTV from infected to naïve hosts. Similar to WNV and DENV, BTV is first ingested by a competent vector, then replicates in the vector, after which it can be transmitted into the following victim [Purse et al 2005]. However, it has not yet been elucidated if vertical transmission applies for BTV [Wilson et al 2007].

Clinical signs of a BTV infection vary according to the serotype and species that are infected. In general, cattle have a higher rate of infection, while sheep suffer from a more severe form of the disease. Clinical symptoms may include appearance of a blue tongue as a result of cyanosis, fever, hemorrhages and ulcerations of the oral and nasal tissue, excessive salivation, inflammation of the coronary band, and weakness and depression [Mellor et al 2008; Wilson et al 2007]. Because of their higher infection rate, cattle serve as the main reservoir for BTV. Cattle can be infected with BTV for several weeks while displaying little or no clinical signs of the disease. This way, transmissions are able to occur without being noticed [Purse et al 2005].

Temperature has many influences on the behavior of *Culicoides*, and on the transmission of BTV. While adult midges start recruiting at temperatures of 12.5ºC, they preferably recruit at temperature ranges of 25ºC to 30ºC. During these warm periods an increase in activity rates of midges can be observed. Temperature also influences the competence of the *Culicoides* vector and the rate of viral replication within individuals [Purse et al 2005]. Another important factor contributing to BTV transmission is the availability of moist [Mellor et al 2008; Purse et al 2005]. Precipitation provides ideal microhabitats and breeding sites consisting of wet, organically enriched soil and mud for *Culicoides* [Purse et al 2005].

In the past few years the distribution of BTV spread at least 800 km northward [Purse et al 2005]. This spread may have been driven by recent changes in European climate that allowed increased virus persistence during winter. BTV outbreaks diminish as weather gets colder which could mean that the vectors died. But after this period the outbreaks reappear which implies that an overwintering mechanism of BTV might be involved [Purse et al 2005; Wilson et al 2007].

Rising temperatures also caused a northward expansion of *Culicoides imicola* [Mellor et al 2007; Purse et al 2005; Wilson et al 2007]. *Culicoides* can be transported hundreds of kilometers by wind [Purse et al 2005], thereby reaching very distant countries. Despite northward expansion of *C. imicola* BTV is observed in areas where this vector cannot be found. This implies that other *Culicoides* vectors in these regions are able to transmit BTV [Mellor et al 2007; Purse et al 2005; Wilson et al 2007].

In times of peril, animal pharmaceutical industries were urged to develop medicines, vaccines or pesticides in order to restrict BTV expansion. So far vaccines against BTV-2, BTV-4, and BTV-8 for cattle and sheep have been developed and are used [intervet.com].

Conclusions and future perspectives

In 2007 the International Panel for Climate Change (IPCC) confirmed that climate change is a consequence of human activities and that it is actually happening, although there are many uncertainties about its consequences in the future. All infections involve a pathogen, host(s) and the environment which all depend on climate change [Epstein 2001]. Climate change is expected to influence the introduction of viral infections into new regions, especially in the northern latitudes. WNV, BTV and DENV have many similarities; they are all transmitted by arthropod vectors i.e. *Culex, Aedes,* and *Culicoides*. These vectors are all influenced by temperature, moist, and the surrounding environment. Temperature rises are occurring globally, therefore the regions that used to be too cold for vectors to manifest themselves are gradually becoming ideal for disease transmission. Furthermore, temperature speeds up the rate of disease transmission, and might expand the range of epidemiology. In the future, increased precipitation and moist will create important breeding sites and microhabitats.

Other characteristics of climate change also influence the spread of vectors to new regions. *Epstein 2001* states that climate change has a negative effect on nature's feedback mechanism, thereby letting dangerous diseases survive. Many have shown that after extreme events clusters of disease infecting insects exist in the affected regions. But climate change also affects the introduction of diseases indirectly. Climate change will alter the environment of both humans and animals, causing them to migrate to other regions, where more diseases lurk.

As climate change is most likely to be inevitable, so is the introduction of viral infections in new regions. For this reason it is crucial that humans – especially in countries where these diseases do not occur much – should be prepared. Using surveillance, everyday movements of vector-borne disease can be followed, and occasional outbreaks are announced as fast as possible so that large epidemics are avoided. Integrated vector management (IVM) is another way to avoid disease infections on an individual as well as on a population scale. The Global Strategic

Framework on Integrated Vector Management sets out new and broad principles and approaches to vector control that are applicable to all vector-borne diseases. IVM avoids the use of pesticides which are bad for the environment, and vector control methods that cannot be afforded by developing countries.

The relation between climate change and prevalence of more virus infections has yet to be determined. It is difficult to predict whether virus infections will increase as climate changes get more severe, because people are still not sure what future climate changes might bring. Therefore, it is crucial that the process of climate change is well-studied and researched. Also, a better understanding for disease transmission by vectors is needed. Meanwhile, the best way to avoid such diseases is by taking preventive actions and applying vector control.

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