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Minireview

MINIREVIEW – Environmental Microbiology

Climate change and vector-borne diseases of public health significance

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One sentence summary: A review of our current knowledge of the potential effects, and evidence for effects of climate change on vector-borne diseases of public health significance.

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ABSTRACT

There has been much debate as to whether or not climate change will have, or has had, any significant effect on risk from vector-borne diseases. The debate on the former has focused on the degree to which occurrence and levels of risk of vector-borne diseases are determined by climate-dependent or independent factors, while the debate on the latter has focused on whether changes in disease incidence are due to climate at all, and/or are attributable to recent climate change. Here I review possible effects of climate change on vector-borne diseases, methods used to predict these effects and the evidence to date of changes in vector-borne disease risks that can be attributed to recent climate change. Predictions have both over- and underestimated the effects of climate change. Mostly under-estimations of effects are due to a focus only on direct effects of climate on disease ecology while more distal effects on society's capacity to control and prevent vector-borne disease are ignored. There is increasing evidence for possible impacts of recent climate change on some vector-borne diseases but for the most part, observed data series are too short (or non-existent), and impacts of climate-independent factors too great, to confidently attribute changing risk to climate change.

Keywords: climate change; vector-borne disease; public health

INTRODUCTION

Ever since the health impacts of climate change have been considered, the impact on vector-borne disease has been at the forefront (Kovats and Haines 1995; Githeko *et al.* 2000). However, that forefront has been a place of much debate and discord amongst scientists, resulting in considerable uncertainty and confusion about the actual or potential future effects of climate change. Clearly, a global concern is impacts of climate change on the 'big two': malaria and dengue, which have now perhaps become the 'big five' of malaria, dengue, yellow fever, chikungunya and Zika. These diseases are significant causes of morbidity and mortality globally (http://www.who.int/mediacentre/factsheets/fs387/en/), and are now mostly transmitted human to human (even though they originally had a zoonotic origin) via *Anopheles* and *Aedes* spp. mosquitoes in tropical and subtropical regions. Vector-borne diseases are intrinsically sensitive to weather and climate, but the debate and uncertainty around impacts of climate change on them focuses on the degree to which weather and climate determine their occurrence and abundance versus efforts by man to control them and their vectors (Lafferty 2009). However, the focus of impacts of climate change directly on the biology of vectors and vector-borne pathogen transmission may be short sighted because socioeconomic impacts of climate change may well affect our capacity to control vector-borne diseases. Furthermore, many vector-borne diseases of public health significance (e.g. Lyme disease, West Nile virus, viral equine encephalitides) are zoonoses maintained by

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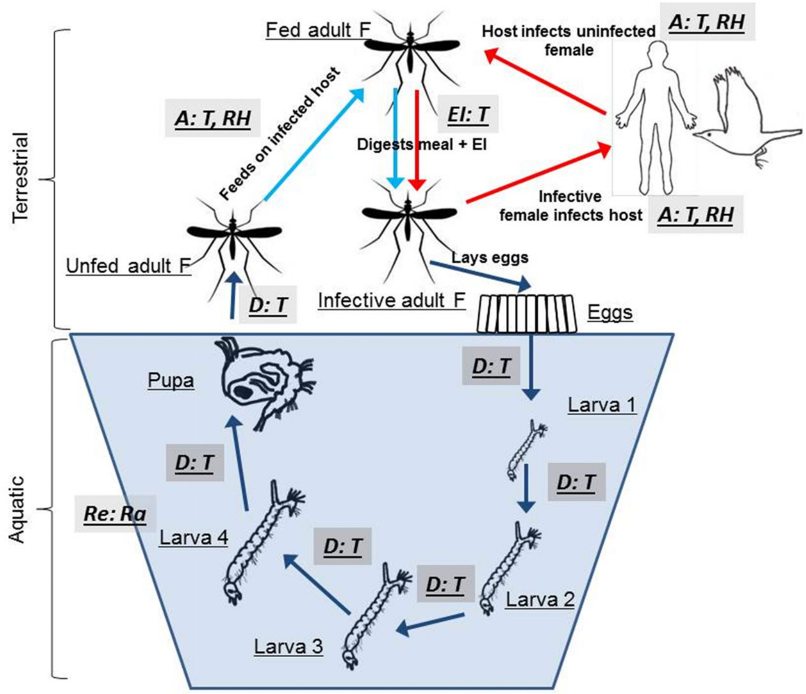

Figure 1. Direct effects of climate and weather on vector populations and vector-borne pathogen transmission illustrated by potential effects on West Nile virus transmission (from Ogden and Lindsay 2016). Dark and pale blue arrows indicate, respectively, development and host finding, while red arrows indicate pathogen transmission. Points at which weather and climate (and potentially climate change) may impact the vector's lifecycle and pathogen transmission cycle are indicated by the grey-filled boxes in which A = effects on activity, D = effects on inter-stadial development rates, EI = effects on the extrinsic incubation period, Re = effects on reproduction, and T = effects of temperature, Ra = effects of rainfall and RH = effects of humidity.

wildlife, and their occurrence is intrinsically less determined by man's control efforts (Ogden *et al.* 2014c).

This review has three main sections that aim to briefly describe, and point the reader to literature on (i) possible effects of climate change on vector-borne diseases; (ii) how we can predict these effects to assist decision making on public health policies and programmes; and (iii) evidence to date for impacts of climate change on some example vector-borne diseases. I conclude with suggested needs for improving our preparedness to respond to anticipated changing risk from vector-borne diseases.

HOW CAN CLIMATE CHANGE AFFECT THE RISK FROM VECTOR-BORNE DISEASES?

Risk from vector-borne diseases is intrinsically sensitive to changes in weather and climate. This has been extensively reviewed (e.g. Medlock and Leach 2015; Parham *et al.* 2015; Ogden and Lindsay 2016), and I briefly summarise these reviews as follows and in Fig. 1. Where, when and how many arthropod vectors are found directly depend on multiple impacts of weather and climate including direct effects of low and high temperatures on vector mortality rates, effects of temperature and humidity on activity and host finding of vectors, effects of temperature on rates of vector development from one life stage to the next and effects of rainfall on availability of breeding habitat for insect vectors. Climate has also indirect impacts on vector occurrence by determining qualities of habitat and availability of animal hosts for vector blood meals. Characteristics of habitat are important for vector survival by determining the availability of refuges for vector survival during weather extremes, which are particularly important for hard-bodied ticks due to their long interstadial development times. Climate and weather impact transmission cycles of vector-borne pathogens directly by effects of temperature on the duration of the extrinsic incubation period of pathogens in insect vectors, which is a crucial factor determining whether or not insect-borne diseases can persist or not. Habitat characteristics also determine the communities of vertebrate hosts, and host biodiversity (and biodiversity change) can impact transmission of those vector-borne zoonoses for which wildlife are the main reservoirs (Cable *et al.* 2017).

Predicted climate changes include increasing temperatures, changes to geographic patterns of rainfall, increasing climate variability, and increasing frequency and severity of extreme weather events (Fig. 2; IPCC 2013). All of the above climate- and weather-dependent factors may, therefore, be impacted by a changing climate resulting in changes to where and when environments may be suitable for vectors and vector-borne pathogens to thrive. The expected result is changes in geographic and seasonal patterns of vector-borne disease occurrence and levels of their risk. Changing dynamics of host communities, vectors and pathogens is expected to also drive changes in the landscape of fitness of different genetic variants of microorganisms and vectors. This may alter the fitness and abundance of strains/genetic variants of pathogens and vectors, and drive 'adaptive' emergence of novel strains and species of public health significance (Gortazar *et al.* 2014). In general, it would be expected that many vector-borne diseases transmitted by flies would be able to respond quickly to changes in weather and climate, because of the short (several weeks long) lifecycles of many dipteran vectors, resulting in increasingly

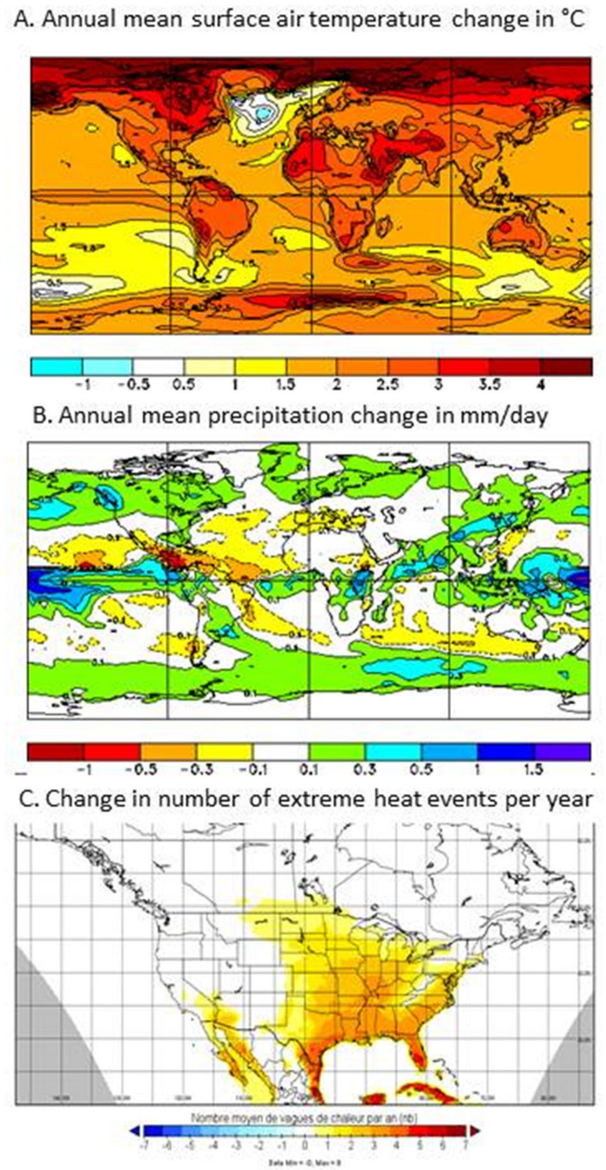

Figure 2. An example of climate model projected climate for 2041–2060 as published in Ogden and Lindsay (2016). (**A**) Projected change in mean surface air temperature (°C) and (**B**) projected change in annual mean precipitation rate in 2041–2060 relative to 1951–1980 as simulated by CGCM3/T47 in the IPCC SRES A1B experiment (five-member ensemble mean using emissions scenario A1B). (**C**) Change in the number of extreme heat events in 2041–2070 compared to 1971–2007 using seven regional climate models of the CORDEX experiment using emission scenario RCP8.5. Images from Environment and Climate Change Canada (http://www.cccma.ec.gc.ca/diagnostics/cgcm3-t47/cgcm3.shtml).

epidemic behaviour of these diseases. In contrast, tick-borne diseases, whose vectors have lifecycles often several years long, would be expected to respond with slower progressive, rather than epidemic, changes in occurrence (Ogden and Lindsay 2016).

Occurrence and levels of risk from vector-borne diseases are also determined by factors that are frequently considered independent of climate and insensitive to climate change. These include efforts to control vector-borne diseases, socioeconomic factors that determine how frequently people are bitten by vectors (e.g. how residences are constructed and air conditioned) or diagnosed and treated after infection (Reiter 2001), and how vectors and vector-borne pathogens are dispersed internationally to permit new niches to be filled (Randolph and Rogers 2010). At least some of these have been put forward as reasons why climate change may be unlikely to impact vector-borne diseases, in particular those transmitted human-mosquito-human such as malaria and dengue (Reiter 2001; Reiter *et al.* 2004). However, climate change may impact the efficacy of vector control (Ogden *et al* 2014c), and climate and climate changes in the past have in general been key drivers of socioeconomic changes (Zhang *et al.* 2011). Such changes can have potentially profound effects on how well our societies are protected from vector-borne diseases (e.g. Reisen *et al.* 2008). Climate change is anticipated to have widespread economic impacts, particularly for vulnerable populations in low- and middle-income countries (e.g. Challinor *et al.* 2007), and such impacts may well impact within-country capacity to control vector-borne diseases directly or by being a driver of conflict (Bowles, Butler and Morisetti 2015). Conflict will likely also drive increased displacement and migration of human populations (Burrows and Kinney 2016), which may enhance dispersal of vector-borne and other diseases into new suitable environments (Odolini *et al.* 2012; Ciervo *et al.* 2016). More subtle interactions between socioeconomic status, the built environment and climate and climate change can impact the occurrence and severity of vector-borne disease outbreaks. For example, drought may reduce risk from vector-borne diseases in rural areas except in resource-poor regions where water storage containers in houses become mosquito breeding habitat exacerbating vector-borne disease risk (Chretien *et al.* 2007). In urban areas, droughts may increase risk from mosquito-borne disease by reducing flushing of eggs and immature mosquitoes out of sewers and drains (reviewed in Yusa *et al.* 2015).

Many vector-borne diseases are already endemic to tropical and subtropical, but not temperate regions. For this reason, and the expectation that climate warming will occur earlier and be more severe toward the poles (IPCC 2013), temperate countries may be those most threatened by emergence and re-emergence of vector-borne diseases. There are broadly three expected threats (Ogden and Lindsay 2016). First, risk from endemic vector-borne diseases may increase due to long-term changes in temperature and rainfall patters, and mosquito-borne diseases may become more epidemic as the vectors and pathogen transmission cycles respond to increasing climate variability and extreme weather events. Second, vector-borne diseases may shift their geographic ranges poleward (or to higher altitudes in mountains) into regions where they are currently not present. Third, climate change may increase the threat of establishment of 'exotic' tropical/subtropical vector-borne diseases (i.e. those endemic to regions far away) by directly increasing the climatic suitability of currently non-endemic countries, by increasing abundance of vectors and pathogens in regions where they are currently endemic (either by direct effects on vector and pathogen biology or indirect socioeconomic effects) and by increased frequency of introduction via increased international migration. An illustration of these possible outcomes using impacts on one country is presented in Fig. 3.

WHY AND HOW DO WE PREDICT EFFECTS OF CLIMATE CHANGE?

In most cases, the greatest effects of climate change, including those on vector-borne diseases, will begin to be felt in the future decades of this century (IPCC 2013). However, all levels of responsibility for public health have an interest in assessing

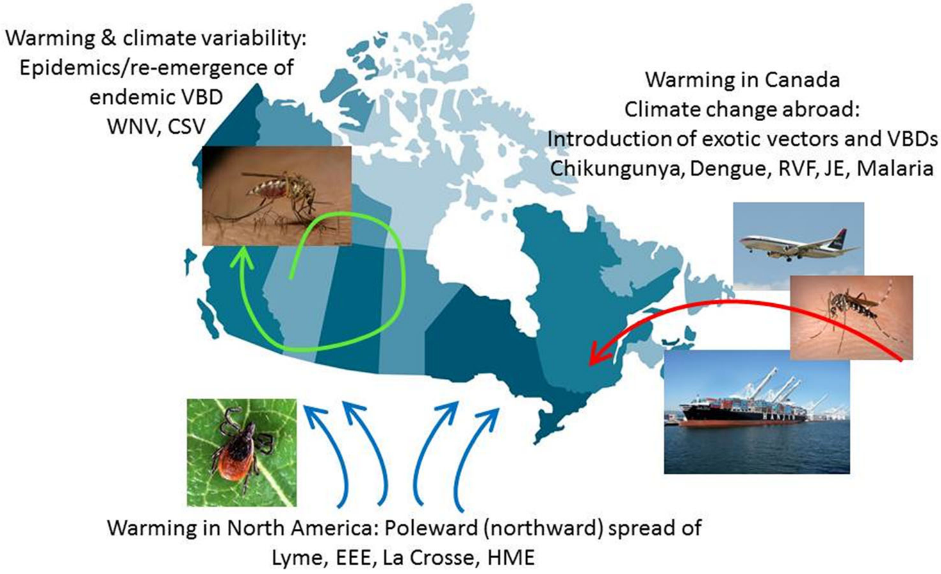

Figure 3. Possible impacts of climate change on changing risks from vector-borne diseases illustrated using possible impacts on Canada as an example. VBD = vector-borne disease, WNV = West Nile virus, CSV = California serogroup viruses, RVF = Rift valley fever, JE = Japanese encephalitis, EEE = eastern equine encephalitis, La Crosse = La Crosse encephalitis, HME = human monocytic ehrlichiosis.

when and where climate change may cause vector-borne diseases to emerge, re-emerge or indeed die out. This foresight information is essential for the development of policies on preparedness for vector-borne disease risks that may arise in the more distant future, the design of public health programmes for more immediate risks and the identification of research gaps (Campbell-Lendrum *et al.* 2015). Predictions involve identifying climatic limits for vectors and vector-borne pathogen transmission, identifying where and when those climatic limits occur at present and then, using global or regional climate models, projecting where and when those same climatic limits, and by inference the vectors and vector-borne pathogens, will occur in the future (Fig. 4). There are two broad ways in which predictive relationships between climate and vector-borne pathogen occurrence are obtained. The first is the use of empirical data on climatic limits often synthesised across the vector lifecycle and pathogen transmission cycle in dynamic mathematical population models (e.g. Ogden *et al.* 2005; Ermert *et al.* 2011). The second is the 'pattern matching' use of field data on occurrence of vectors and pathogens to find quantitative associations between climate data and vector/pathogen presence (using ecological niche modelling methods: Peterson 2003) or presence/absence (using statistical methods: Lorenz *et al.* 2014). For these methods, current climate and climate-independent data are obtained from interpolated ground-level observations or from satellite data, which are linked to field observations of vectors and pathogens using geographic information systems (e.g. Gabriele-Rivet *et al.* 2017).

In either case, predictions that are made while accounting for climate independent factors are those that are, by and large, the most useful. Predictions that are made using mathematical models without considering the modifying effects of climate-independent factors may well overestimate effects of climate change. Conversely, predictions made by pattern-matching methods on the basis of current distributions of vector-borne diseases may well underestimate potential climate change effects if (i) distributions are highly controlled by seemingly climate-independent factors and (ii) if climate change will actually have indirect impacts on the factors controlling vector or pathogen occurrence. Unsurprisingly, when both overpredicting mathematical models and possibly underpredicting pattern-matching methods are used for the same vector-borne disease, they can yield starkly different results. This has been the case for predictions of climate change impacts on malaria (Martens *et al* 1995; Rogers and Randolph 2000), and these widely different assessments, compounded by the use of models that are considered too simplistic (Tanser, Sharp and le Sueur 2003; Reiter *et al.* 2004), have contributed to considerable debate on potential impacts of climate change and vector-borne diseases (Lafferty 2009).

The notion that 'all models are wrong but some are useful' applies to those used to predict the effects of climate change on vector-borne diseases. Our confidence in using them to develop policies and programmes increases with (i) validation of the deduced climate-vector/vector-borne disease relationship using data independent of those employed in calibrating the models; (ii) exploration of uncertainty in model predictions arising from uncertainty in model parameter estimates (e.g. Parham and Michael 2010; Beale and Lennon 2012); (iii) accounting for climate-independent factors in model construction or in simulations (Woolhouse 2011; Fox *et al.* 2012); (iv) exploration of assemblages of climate models that may provide a range of projected future climates that are equally possible (McPherson *et al.* 2017); and, eventually (v) validation by observed effects of climate change (see below).

WHAT IS THE EVIDENCE TO DATE OF EFFECTS OF CLIMATE CHANGE ON VECTOR-BORNE DISEASES OF PUBLIC HEALTH SIGNIFICANCE?

Clearly, the most powerful driver for public health policy on climate change and vector-borne diseases would be the presence of empirical evidence. However, amongst the most contentious issues around climate change and vector-borne diseases is whether or not there is evidence to date for effects

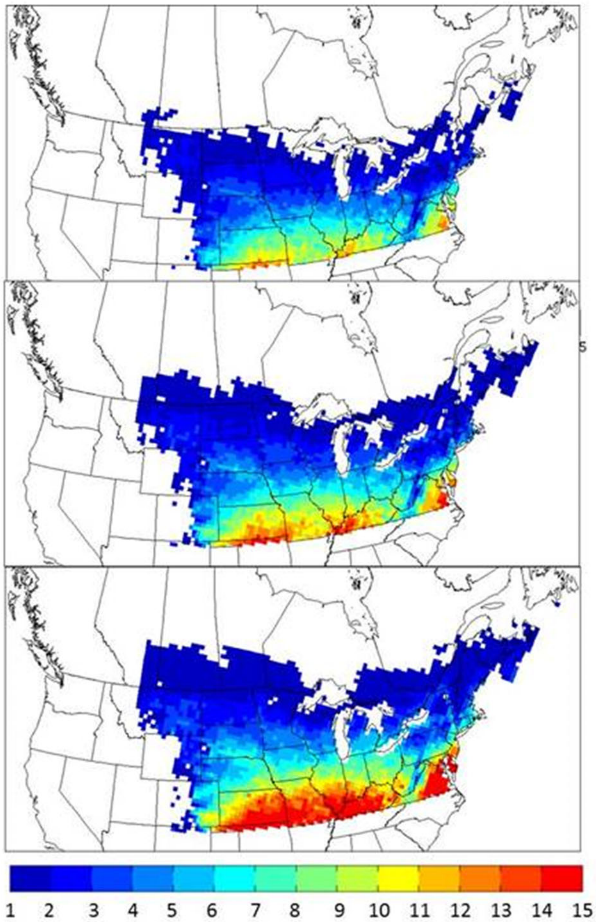

Figure 4. An example of a model-based prediction of how projected climate change may impact the distribution of a disease vector (in this case, the Lyme disease tick vector *I. scapularis*) at a continental scale reproduced from Ogden *et al.* (2014c). The level of risk, as indicated by the colour scale, is measured as the basic reproduction number (R_0) of the tick. Below an R_0 of 1, populations of the tick would not be expected to survive. The upper map shows R_0 values estimated from observed climate (for 1971–2000), and the lower two show R_0 values estimated from projected climate obtained from the CRCM4.2.3 regional climate model following the SRES A2 greenhouse gas emission scenario for 2011 to 2040 (middle panel) and 2041 to 2070 (bottom panel). Within the zones where R_0 of *I. scapularis* is >1, geographic occurrence of Lyme disease risk is also limited by other environmental variables.

of climate change on their occurrence. Evidence requires a two-step process—detection of a change in the risk from a vector-borne disease and attribution to recent climatic changes (Ebi *et al.* 2017b). The combination of detection and attribution requires systematic surveillance or other kind of monitoring for periods of time (usually decades) needed to compare changing disease patterns against changing climate patterns. Datasets of a suitable quality and duration for this purpose are rare so, combined with the fact that most of the planet has only relatively recently experienced the first effects of a changing climate, it may be unsurprising that attribution of changes in vector-borne disease occurrence and risk levels to recent climate change is rare.

There is evidence for impacts of climate change on some vector-borne diseases (whether or not they are of significance for public health), and one of the earliest examples is the expansion of Blue-tongue virus (BTV) into a warming Europe from North Africa. Mechanistically, the range expansion of BTV is thought to be a combined effect of climate warming increasing climate suitability for BTV *Culicoides* spp. vectors and for BTV transmission by, and persistence in, vectors over winter (Purse *et al.* 2005). There has been much effort to seek similar evidence for major vector-borne diseases such as malaria, but strong evidence for these has proved elusive. Nevertheless, for some vector-borne diseases there is early evidence of impacts of climate change. In the following, I briefly review some examples of efforts to date to detect and attribute effects of climate change on vector-borne diseases.

Changes in incidence of tropical diseases; the case of malaria: Detection and attribution of effects of climate change on malaria has been as controversial as the earlier debate on prediction of climate change effects. It is well recognised that the current geographic distribution of malaria is greatly determined by past and current efforts to control both vectors and transmission in addition to climate (Reiter 2001; Reiter *et al.* 2004). Therefore, much effort has focused on possible effects of climate change on driving a change in the upper altitudinal limit for transmission in highlands of eastern Africa. In this region, the strong seasonal pattern of malaria incidence indicates its susceptibility to climate (Hay, Snow and Rogers 1998). The mechanism of climate sensitivity relevant to climate change in this region is mostly the interacting effects of temperature on (i) the extrinsic incubation period of malaria parasites (the warmer, the shorter it is); (ii) the survival of mosquitoes (at this altitude, the warmer the greater it is); and (iii) the length of the gonotrophic cycle (the warmer, the shorter it is) and thus the biting rate (the warmer the greater it is) (Lindsay and Burley 1996). Surveillance has clearly identified interannual variations in incidence in this region, and some researchers have associated these with weather or climate patterns (Zhou *et al.* 2004). However, there has been controversy regarding the evidence that these changes may have been associated with climate versus climate-independent factors such as development of resistance to antimalarial drugs (Hay *et al.* 2002; Reiter *et al.* 2004). Pascual *et al.* (2006) then Stern *et al.* (2011) showed, with a longer dataset, more clear evidence of temperature increase trends in recent years and associations with malaria incidence, with similar evidence in different regions of the world (Siraj *et al.* 2014). These studies, and the debate, have occurred during a period where global malaria incidence has declined due mainly to control efforts (Gething *et al.* 2010), which underlines the difficulties in attributing climate change impacts using surveillance data. First, the use of human case data for these purposes is not without difficulties (reviewed in Ebi *et al.* 2017a). These include issues of sensitivity and specificity of the diagnosis itself (the latter being particularly relevant to malaria in Africa where overdiagnosis is likely: Ghai *et al.* 2016), as well as possible issues of precision in identifying place and time of infection, and the impact of a wide range of human behavioural and socioeconomic factors on risk of exposure to infection (Reiter 2001). Entomological surveillance data may be more likely to detect direct effects of climate and climate change as long as mosquito control (rather than bite prevention methods such as bednets) is not a major component of malaria control. However, entomological surveillance is resource intensive and expensive if it is to be conducted with levels of sampling frequency and geographic coverage needed to have the power to detect expected seasonal, interannual and geographic variations (e.g. ECDC 2012). In contrast, human case data may be passively collected in healthcare systems and are often relatively freely available in circumstances where data privacy is not an issue (Ebi *et al.* 2017a).

Tick-borne encephalitis (TBE): The possible role of climate change in changes in incidence of TBE in Europe has been a source of debate almost as intense as that around malaria (e.g. Hay 2001; Lindgren and Gustafson 2001; Randolph 2004, 2010). This debate has focused on evidence for climate change impacts on increases in incidence of human cases (Hay 2001; Lindgren and Gustafson 2001), and in particular on alternative explanations for observed changes in incidence. Apart from the effects of anticipated climate change on the geographic range of the tick vectors, a warming climate has been predicted to impact whether or not TBE transmission cycles can persist via effects on seasonality of tick activity where *Ixodes ricinus* is the vector. The short period of infectivity of rodent hosts means that transmission is only efficient when the seasonal activity periods of nymphal *I. ricinus* ticks infecting the rodents, and larval ticks acquiring infection from the rodents, are very synchronous (Randolph *et al.* 1999). Projected effects of climate change in central and northern Europe are a northward range shift (rather than simply expansion) in the early decades of this century, followed by an increasingly fragmented occurrence of transmission cycles as warming continues (Randolph and Rogers 2000). There are a number of reports that provide some evidence for changing geographic patterns of vector ticks and TBE incidence that may be consistent with climate change (e.g. Daniel *et al.* 2009; Tokarevich *et al.* 2011, 2017), and a recent northward range shift in Sweden (Lindgren and Gustafson 2001) would be consistent with the projected early effects of climate change (Randolph and Rogers 2000). More recently, analyses of human case surveillance data have identified (i) changes in altitude of TBE occurrence and (ii) spreading of the pattern of seasonal occurrence of TBE cases, as well as changes in incidence, which may all be consistent with effects of climate change (Kříž *et al.* 2015). The authors do not state that these data prove climate change effects, but they underline that the observed patterns mean that climate change effects are plausible. However, in some parts of Europe, recent increases in TBE incidence have most likely been associated with socioeconomic changes, landscape change and other factors that have changed rates of contact between the human population and infective ticks (Sumilo *et al.* 2007; Korenberg 2009; Zeman, Pazdiora and Beneš 2010; Zeman and Benes 2013).

Lyme disease: Surveillance systems and targeted studies in Canada and Sweden have been able to detect recent northward range expansion of tick vectors of Lyme disease (*I. scapularis* and *I. ricinus* respectively) (Lindgren, Tälleklint and Polfeldt 2000; Ogden *et al.* 2010, 2014a; Leighton *et al.* 2012). Furthermore, there is more solid evidence, in the form of geographic patterns and timing of expansion related to regional warming, that changes in the northern limits of these vectors can be attributed to recent warming climate (Lindgren, Tälleklint and Polfeldt 2000; Ebi *et al.* 2017b). Expansion of the range of *I. scapularis* is attributed to the effects of a warming climate on shortening the lifecycle of the tick rather that direct effects of warming temperatures on tick survival (Ogden 2014), while the precise mechanism of effect on *I. ricinus* has not yet been elucidated. *Borrelia burgdorferi* transmission cycles are robust, particularly when compared to those for TBE, because of the long duration of infectivity of infected hosts, and the very wide host range (including birds) for some *B. burgdorferi* genospecies (Kurtenbach *et al.* 2006). *Borrelia burgdorferi* transmission cycles are therefore less affected by changes in tick seasonality, and, due to the feeding behaviour of the tick, considerations of climate effects on the extrinsic incubation period are mostly irrelevant (reviewed in Ogden, Mechai and Margos 2013; Ogden and Lindsay 2016). Furthermore, the tick vectors and some *B. burgdorferi* genospecies are readily dispersed over long distances by migratory birds (Ogden, Mechai and Margos 2013). Likely for these reasons, at the northern edge of their geographic ranges, northward range expansion of *B. burgdorferi* has followed that of the tick vectors (Ogden, Lindsay and Leighton 2013). In Canada at least, expansion of the range of the tick, followed by that of *B. burgdorferi,* has been accompanied by an increase in human Lyme disease cases (Ogden *et al.* 2014a).

Incursion of tropical/subtropical vector-borne diseases into temperate zones: A key fear for public health in temperate zone countries is that a tropical/subtropical vector-borne disease, that is highly transmissible human to human via mosquitoes, will become established due to effects of climate change. This possibility has received much attention in terms of qualitative (e.g. Rezza 2014; Medlock and Leach 2015; Ebi and Nealon 2016) and quantitative (or at least data-driven) assessments of the risk of endemic/autochthonous transmission of tropical/subtropical vectors and vector-borne diseases (e.g. Caminade *et al.* 2012; Ogden *et al.* 2014b; Ng *et al.* 2017). There have clearly been invasions of tropical/subtropical vectors and vector-borne diseases into temperate regions, and these include the invasion and spread of West Nile virus in North America (Kilpatrick 2011; Reisen 2013), an outbreak of chikungunya in Italy (Angelini *et al.* 2007) and autochthonous cases of dengue and Leishmaniasis in Europe (Naucke *et al.* 2008; Tomasello and Schlagenhauf 2013; Schaffner and Mathis 2014). However, while we can predict that climate change may increase the probability of these events (via direct impacts on local environmental suitability and indirect effects on migration and control efforts in endemic countries), the extent to which these events to date have been associated with climate change is unknown. A range of climate-independent plausible explanations include increased travel and globalisation of trade increasing introduction probabilities, adaptation of vectors and virus to temperate climates, and the occurrence of unexpected suitable niches for exotic vectors (Medlock and Leach 2015).

CONCLUSION

Efforts to predict impacts of climate change on vector-borne diseases must continue to drive the development of public health policies and programmes that reduce the impact of emerging and re-emerging vector-borne diseases. Ideally such model-based assessments of risk should include consideration of climate-dependent and independent factors that directly affect vector-borne disease transmission, and also more distal effects of climate change on vector-borne disease that may arise due to socioeconomic impacts of climate change on our societies. Surveillance for vector-borne diseases needs to be implemented but with intensity of effort tailored towards the immediate risk level (Murphy, Vaux and Medlock 2013; Kampen *et al.* 2015). In many circumstances, this will involve entomological surveillance, or other methods such as sentinel animal surveillance, that provides an early warning in advance of human disease cases and helps to validate and improve model-based predictions. For attribution of changing vector-borne disease risks to climate change, long-term (i.e. decades) surveillance programmes would need to be planned for. Lastly, public health jurisdictions at risk need the prevention and control tools to protect the health of the public in response to emerging and re-emerging vector-borne disease, at which point whether or not the underlying cause is climate change is largely irrelevant.

Conflicts of interest. None declared.

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