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Review

Climate change and the epidemiology of selected tick-borne and mosquito-borne diseases: update from the International Society of Dermatology Climate Change Task Force

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Abstract

Climate change refers to variation in the climate of a specific region or globally over time. A change has been reported in the epidemiology of tick- and mosquito-borne diseases in recent decades. Investigators have postulated that this effect may be associated with climate change. We reviewed the English-language literature describing changes in the epidemiology of specific tick- and mosquito-borne diseases, including the tick-borne diseases of Lyme disease, tularemia, Crimean-Congo hemorrhagic fever, Mediterranean spotted fever, and Rocky Mountain spotted fever and the mosquito-borne diseases of dengue, malaria, West Nile virus infection, Ross River virus disease, and Barmah Forest virus disease. We postulate that the changing epidemiology of tick- and mosquito-borne diseases is related to climate change.

Introduction

One of the most pressing environmental issues of the twenty-first century is global climate change, a term referring to variation in climate in a specific region or globally over time. A generally accepted concept espouses that the large quantities of greenhouse gases emitted into the atmosphere are a major cause of climate change. This change in climate is associated with a rise in temperature, changes in relative humidity, a rise in sea levels, and more extreme weather events.[1]

The epidemiology of tick- and mosquito-borne diseases has been changing in recent decades. It had been speculated that climate change could lead to a change in the epidemiology of these diseases. Tick and mosquito development, survival, and geographic distribution have been observed to be highly sensitive to climate and ecologic changes.[2–8] Some climate models, for instance, suggest a geographic shift in disease vectors, their pathogens, and the transmission of their respective diseases as the climate warms.[2–5,8–10] Tick- and mosquito-borne diseases are associated with the development of cutaneous manifestations, including erythema migrans, ulcerations, vesicles, bullae, eschar, maculopapular rash, and a papular or petechial manifestation among persons infected, hence the relevance of this subject to the specialty of dermatology.

One of the main purposes for the International Society of Dermatology Climate Change Task Force is to track which skin or skin-related diseases could be affected by changes in climate. The aim of the present study was to gather available literature describing changes in the epidemiology of tick- and mosquito-borne diseases that cause cutaneous manifestations, which may be associated with climate change.

Materials and methods

We searched PubMed using the search term climate change OR climate variability OR global warming OR temperature OR dry OR rainfall AND ticks OR mosquitoes OR disease OR skin. English-language literature was included. We also searched the International Society of Dermatology website library (http://www.intsocderm.org) on climate change for further articles, as well as the US Centers for Disease Control and Prevention website for further information on tick and mosquito vectors, their pathogens, and their current geographical distributions. For this study, we included the following diseases: (i) the tick-borne diseases of Lyme disease, tularemia, Crimean-Congo hemorrhagic fever (CCHF), Mediterranean spotted fever (MSF), and Rocky Mountain spotted fever, and (ii) the mosquito-borne diseases of dengue, malaria, West Nile virus (WNV) infection, Ross River virus (RRV) disease, and Barmah Forest virus (BFV)

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disease. Owing to the reference limit of the present report, a maximum of four referenced articles for each disease were included. We abstracted the following data: disease, vector species (ticks or mosquitoes), their pathogens, geographical areas, cutaneous manifestations, and impact of climate change or climate variability on the vector, their pathogens or host, and the epidemiology of their respective diseases.

Results

Most of the included studies had described how changes in climate could affect disease vectors (i.e., ticks and mosquitoes) and their pathogens, hosts, and respective diseases. Table 1 summarizes the abstracted data regarding tick-borne diseases,[2,3,9–30] and Table 2 summarizes the abstracted data regarding mosquito-borne diseases.[4–8,31–49]

Discussion

Within the past decades, an increase in the number of tick-borne and mosquito-borne diseases has been reported in certain areas in the world. The emergence of these diseases has been occurring simultaneously with a warming climate. The

Table 1 Climate change effect on tick-borne diseases

Disease	Species of tick	Pathogen	Skin manifestation	Source	Climate change effect and/or predicted effect on vectors, hosts, pathogens, and epidemiology of disease
Lyme disease	North America: *Ixodes scapularis* Europe: *Ixodes ricinus*	North America: *Borrelia burgdorferi sensu stricto* Europe and Asia: *Borrelia afzelii* or *Borrelia garinii*	Erythema migrans, acrodermatitis chronica atrophicans[11]	Roy-Dufresne *et al.*[9]	Northward expansion of geographical range of host in Canada in future
				Ogden *et al.*[2]	Northward expansion of geographical range of *I. scapularis* in Canada in future
				Robinson *et al.*[30]	Possible increased risk of disease in Minnesota, USA, in future
				Simon *et al.*[10]	Northward expansion of *Borrelia burgdorferi* in Canada in future
Tularemia[a]	*Amblyomma, Dermacentor, Haemaphysalis, Ixodes*	*Francisella tularensis*	Ulceration[12]	Nakazawa *et al.*[13]	Possible northward expansion of geographical range of tularemia in USA in future
				Hueffer *et al.*[14]	Possible increased risk of disease in Alaska, USA, in future
				Eisen *et al.*[15]	Disease incidence was positively associated with coverage by dry, forested habitat suitable for ticks in some US states
				Palo *et al.*[16]	No association between the NAO index, number of cases, and density of hares in future
Crimean-Congo hemorrhagic fever	*Hyalomma*	Virus family: *Bunyaviridae* Genus: *Nairovirus*	Flushed face, petechiae, icterus[17]	Ansari *et al.*[18]	Mean temperature, rainfall, and relative humidity were associated with higher monthly incidence in Iran
				Mostafavi *et al.*[19]	Maximum temperature and relative humidity in previous months were positively associated with disease occurrence
				Gale *et al.*[20]	No predicted increase in risk of incursion in livestock through infected *Hyalomma* ticks in Europe in future

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Table 1 Continued

Disease	Species of tick	Pathogen	Skin manifestation	Source	Climate change effect and/or predicted effect on vectors, hosts, pathogens, and epidemiology of disease
				Estrada-Pena and Venzal[3]	Northward expansion of geographical range of *Hyalomma marginatum* in Mediterranean Sea region in future
Mediterranean spotted fever, also called Boutonneuse fever	*Rhipicephalus sanguineus*	*Rickettsia conorii*	Eschar (usually single)[21]	Vescio *et al.*[22]	Rise in mean maximum temperature has been associated with increase in disease incidence 1 year later in northern Sardinia, Greece
				Raoult *et al.*[23]	Annual disease incidence was positively associated with average temperature of preceding year and was negatively correlated with days with frost in south of France
				de Sousa *et al.*[24]	Higher temperature and low precipitation are affecting epidemiology in Portugal
				Espejo Arenas *et al.*[25]	Higher temperature and low precipitation are affecting epidemiology in Spain
Rocky mountain spotted fever, also called tick typhus	Commonest vector: *Dermacentor variabilis* Other vectors: *Dermacentor andersoni*, *Rhipicephalus sanguineus*	*Rickettsia rickettsii*	Maculopapular rash; later, a papular or petechial rash can occur[21]	Parola *et al.*[26]	Higher temperature is associated with increase in aggressiveness of *R. sanguineus*
				Kaplan and Newhouse[27]	Highest incidence in mid-May and mid-July in oak-hickory-pine, oak-hickory, and Appalachian zones
				Taylor *et al.*[28]	Highest incidence is in the warm months from April to August in some US states
				Hidalgo *et al.*[29]	Disease outbreaks during the dry season (February–April) in Córdoba, Colombia

NAO, North Atlantic Oscillation.
[a]Tularemia can also be transmitted by deer fly or by inoculation through the skin, oropharyngeal mucosa, or conjunctiva through contaminated water, blood, or tissue.

question is whether climate change is to blame for this change in disease epidemiology.

Could climate change be responsible? Perhaps so, as they are temporally related. However, changes in the geographic distribution and epidemiology of tick- and mosquito-borne diseases are not uniform across all regions and vector species. In addition, other factors such as urbanization and human behavior and demographic factors may also have a role in the changing epidemiology of these diseases.

Tick-borne diseases

Tick-borne diseases are mostly reported in North America, Europe, and Asia and around the Mediterranean Sea. Climate models have predicted that future climate change could attribute to northern range expansions of *Ixodes* ticks,[2] their pathogens,[10] and reservoir hosts[9] of Lyme disease in Canada. Changes in temperatures and forest habitat are predicted to increase the risk of Lyme disease in Minnesota in the USA.[30] Other climate models have also suggested that climate change could attribute

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Table 2 Climate change effects on mosquito-borne diseases

Disease	Species of mosquito	Pathogen	Skin manifestation	Source	Climate change effect or predicted effects on vectors, hosts, pathogens, and epidemiology of disease
Dengue	*Aedes*	Family: *Flaviviridae* Genus: *Flavivirus*	Maculopapular rash, but petechial or scarlatiniform rash can also develop	Xuan le *et al.*[32]	Rainfall and humidity associated with increased disease risk in Haiphong, Vietnam
			Dengue hemorrhagic fever may present with usual manifestations, such as epistaxis, petechia, purpura, and ecchymosis[31]	Williams *et al.*[33]	Moderate increases in temperature (1 °C) could, but not necessarily, attribute to higher disease risk in Malaysia
				Proestos *et al.*[4]	Possible expansion of geographical range of *Aedes albopictus* in eastern Brazil, eastern USA, western and central Europe, and eastern China in future, while other areas will have reduction
				Campbell *et al.*[5]	Possible shift in geographical range of *Aedes aegypti* and *A albopictus* in North America, southern South America, and Europe with future climate change
Malaria[a]	*Anopheles*	*Plasmodium* spp.	Urticaria, erythema, angioedema, petechiae, purpura, jaundice[31]	Martens *et al.*[6]	Geographical distribution of disease is predicted to shift to higher altitudes with future climate change
				Caminade *et al.*[7]	Globally, distribution of malaria is predicted to shift with future climate change; higher risk in African highlands, central Europe, and North America
				Hay *et al.*[34]	No association found between temperature, rainfall, vapor pressure, and number of months suitable for *Plasmodium falciparum* and disease occurrence in East Africa
				Tanser *et al.*[35]	Climate models predicted latitudinal extensions and increase in disease in Africa in future
West Nile virus infection	*Culex*	Family: *Flaviviridae* Genus: *Flavivirus*	Maculopapular rash[36]	Paz[37]	Extreme high temperatures were associated with increased incidence in Israel
				Jones *et al.*[8]	Survival of *Culex pipiens* in North America was negatively affected by rainfall
				Morin and Comrie[38]	Lengthening of mosquito season in USA, however, with decrease in summer populations in future
				Platonov *et al.*[39]	The number of West Nile virus seemed to be higher in years with mild winter and hot summer in Volgograd, Russia
Ross River virus disease (RRVD)	*Aedes*, *Culex*	Family: *Togaviridae* Genus: *Alphavirus*	Maculopapular rash[40]	Hu *et al.*[41]	Monthly precipitation was associated with RRVD transmission in Brisbane, Australia, in climate models
				Tong *et al.*[42]	Results of cross-correlations climate variability (including tidal level) were significantly associated with RRVD incidence in Townsville region of Australia
				Tong and Hu[43]	Incidence of RRVD was significantly associated with rainfall, temperature, relative humidity, and high tide in coastline region and with rainfall and relative humidity in inland cities of Queensland, Australia
				Werner *et al.*[44]	Temperature was most significant driver of increase in RRVD in Tasmania, Australia

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Table 2 Continued

Disease	Species of mosquito	Pathogen	Skin manifestation	Source	Climate change effect or predicted effects on vectors, hosts, pathogens, and epidemiology of disease
Barmah Forest virus (BFV) disease	*Culex, Aedes, Anopheles, Coquillettide*	Family: *Togaviridae* Genus: *Alphavirus*	Maculopapular rash[45]	Naish *et al.*[46]	Risks of acquiring BFV are increasing with climate change in some areas while others are decreasing Queensland, Australia
				Naish *et al.*[47]	Maximum and minimum temperature, rainfall, relative humidity, and high and low tide are reported to be significantly associated with BFV incidence at lags of 0–2 months in Queensland, Australia
				Naish *et al.*[48]	Minimum temperature and high tide affect transmission BFV in Gladstone Region, Australia
				Doggett *et al.*[49]	Above-average rainfall coupled with high tides attributed to extraordinarily large populations of *Aedes vigilax* in south coast of New South Wales, Australia, and caused disease outbreaks

[a]Cutaneous manifestations are rarely reported in patients with malaria; however, listed skin manifestations have been reported in the literature.

to northern range expansions of tularemia in the USA.[13,14] Interestingly, tularemia incidence was found to be positively associated with coverage by dry, forested habitat suitable for ticks for the US states of Oklahoma, Kansas, Nebraska, Arkansas, and Missouri but not Illinois, Indiana, Kentucky, and Tennessee.[15] Investigators have stated that an increase in the North Atlantic Oscillation Index with future warming will not facilitate a higher frequency of tularemia in Sweden.[16]

For Europe, climate change is not predicted to increase the overall risk of incursion of CCHF in livestock through *Hyalomma*-infected ticks introduced by migratory bird species.[20] Instead, in the Mediterranean Sea, climate change is likely to expand the geographic range for *Hyalomma marginatum* northward.[3] In Iran, changes in mean temperature, rainfall, and maximum relative humidity have been shown to be significantly associated with the monthly incidence of CCHF.[18] In Zabol and Zahedan, Iran, the maximum temperature and relative humidity in previous months have been found to be positively associated with the occurrence of CCHF.[19]

The occurrence of Rocky Mountain spotted fever is affected by climate and by ecologic and geophysical variables.[27] Increased temperature has been noted to be associated with increases in the aggressiveness of the brown dog tick.[26] A peak in the number of Rocky Mountain spotted fever cases in some US states (Arkansas, Oklahoma, and Texas) was found in the warm months of April through August, with the highest number in May or June.[28] Similarly, in Colombia, Rocky Mountain spotted fever outbreak is reported to occur during the dry season, from February through April.[29]

For MSF, a 1 °C increase in the mean maximum temperature levels during summer has been correlated with an increase of 32% in MSF incidence a year later in northern Sardinia, Greece.[22] The annual incidence of MSF in Marseille, southern France, was positively associated with the average temperature of the preceding year and was negatively correlated with number of days with frost.[23] In Spain and Portugal as well, the epidemiology of MSF appears to be associated with climate change, particularly with higher temperatures and low precipitation.[24,25] (Table 1 summarizes these data.)

Mosquito-borne diseases

Mosquito-borne diseases are reported in Africa, India, Asia, China, parts of the Pacific Ocean region and Australia, parts of Europe and the Middle East, and the Americas. For dengue fever, changes in rainfall and humidity have been associated with increased risk in Vietnam.[32] In Malaysia, a moderate increase in temperature (1 °C) was not necessarily attributed to increased dengue incidence.[33] Climate models also predicted that future changes in climate could influence the geographic range of the disease vectors of dengue fever in the Americas and Europe, as well as eastern China.[4,5] Other climate models have suggested that climate change could attribute to northern range expansions of malaria.[6,7,35] Further, in Africa, climate models estimate a continental increase of 16–28% in person-months of malaria by 2100.[35] Yet, long-term meteorologic trends in four high-altitude sites in East Africa, where increases in malaria have been reported in the past two decades, have shown no association with temperature, rainfall, vapor pressure, and number of months suitable for the pathogen of malaria.[34]

For WNV, extremely high temperatures have been associated with increased incidence in Israel.[37] Using a climate-driven mosquito population model, investigators have noted that future climate change could lengthen the mosquito season, with a decrease in summer mosquito populations in the USA.[38] In Volgogard, Russia, the number of WNV infections seems to be greater in the years with mild winters and hot summers.[39] In North America, the survival of *Culex pipiens* – the pathogen of WNV – was negatively affected by rainfall.[8]

In Brisbane, Australia, climate models have found that monthly precipitation was significantly associated with RRV transmission.[41] In other parts of Australia, climate variability such as rainfall, maximum and minimum temperature, and relative humidity, as well as high tide, was also associated with the incidence of RRV disease.[42,43] In Tasmania, Australia, temperature was found to be the most significant factor in the number of RRV cases in 1 month, attributing to a 23.2% increase above the long-term case average.[44] In areas of Queensland, Australia, the risk of acquiring BFV disease is increasing with climate change, while in other areas of the country, the risk may decrease in the future.[46] In addition, other climate conditions, such as temperatures, rainfall, relative humidity, and tides, were reported to affect the transmission of BFV disease.[47,48] Finally, above-average rainfall coupled with high tides has been associated with an extraordinarily large population of *Aedes vigilax* along the south coast of New South Wales, Australia, and with outbreaks of BFV disease.[49]

Conclusion

Global climate change is associated with many changes. Substantial evidence indicates that a change in the epidemiology of tick-borne and mosquito-borne disease in specific areas of the world could be associated with climate change, although this conclusion is still debated.

Questions (answers provided after references)

(1) Climate change is defined as which of the following descriptions?
- A Variation in climate in a specific region or globally over time
- B Variation in climate in a specific region over a year
- C Prolonged warming in the Pacific Ocean
- D Changes in normally occurring weather pattern
- E Variation in rainfall globally

(2) Which of the following mosquito species typically transmit malaria?
- A *Culex*
- B *Aedes*
- C *Coquillettide*
- D *Anopheles*
- E Psorophora

(3) In which of the following diseases can a scarlatiniform rash develop?
- A Dengue
- B Lyme disease
- C Tularemia
- D Barmah Forest virus disease
- E Mediterranean spotted fever

(4) Which of the following tick species typically transmit Lyme disease?
- A *Ixodes*
- B *Amblyomma*
- C *Dermacentor*
- D *Haemaphysalis*
- E All of the above

(5) Which of the following cutaneous manifestations is associated with Crimean-Congo hemorrhagic fever?
- A Eschar
- B Maculopapular rash
- C Flushed face
- D Ulceration
- E Acrodermatitis chronica atrophicans

(6) Which of the following cutaneous manifestations is associated with Lyme disease?
- A Urticaria
- B Erythema migrans
- C Jaundice
- D Scarlatiniform rash
- E Petechiae

(7) In which of the following tick-borne diseases does a person typically have an eschar?
- A Mediterranean spotted fever
- B Lyme disease
- C Tularemia
- D Crimean-Congo hemorrhagic fever
- E None of the above

(8) In which of the following tick- or mosquito-borne diseases can a maculopapular rash occur?
- A Dengue
- B Rocky Mountain spotted fever
- C West Nile virus infection
- D Barmah Forest virus disease
- E All of the above

(9) Which of the following cutaneous manifestations is associated with tularemia?
- A Dermatitis
- B Urticaria
- C Jaundice
- D Ulceration
- E Acrodermatitis chronica atrophicans

(10) All of the following areas are typically associated with mosquito-borne disease *except* which area?
- A South America
- B Australia
- C Scandinavian countries
- D Asia
- E Africa

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Answers

1 (A), 2 (D), 3 (A), 4 (A), 5 (C), 6 (B), 7 (A), 8 (E), 9 (D), 10 (C).

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