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Impact of Climate Change on Ticks and Ticks-Borne Zoonotic Diseases

AUTHORS DETAIL

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INTRODUCTION

Climate change has emerged as the most serious global threat in the last few decades. It has wide range of impacts limited not only to the environment or the ecosystem but also on the socioeconomics and the politics of the world. It is an inter-governmental issue which needs an organized and cooperative response from all the countries (Dantas-Torres 2015; Abbass et al. 2022). In 2015, United Nations Framework Convention on Climate Change (UNFCCC) in Paris struck an agreement between 195 countries to play their role in fighting the global climatic change by reducing emission of greenhouse gases and limiting the rise in temperature to 1.5°C (Burleson 2016).

The changing earth's climate like global warming, irregular weather patterns, changes in humidity and pressure levels, elevated sea level and melting of glaciers poses sustainable threat to the ecosystem. It causes disappearance of biological communities, changes in biodiversity and alterations in the geographical distributions of species ultimately affecting the human well-being (Dantas-Torres 2015; Pedrono et al. 2016; Khanal et al. 2022). The similar is the case with ticks which spend a major part of their life off from their hosts in the environment (Gray et al. 2009; Nuttall 2021). Their survival in the environment is dependent on the host availability and climatic factors like temperature, humidity, and vegetation coverage (Tomkins et al. 2014; Kaba 2022). Thus, the climate change directly affects the distribution, abundance and the host-seeking behaviour of ticks (Leger et al. 2013).

In the last few decades, the prevalence of ticks has increased showing the positive effect of climate change towards ticks (Cunze et al. 2022). Apart from increased tick prevalence, the impact of climate change on the host's behaviour is also an important factor in the emergence of a disease (Gray and Ogden 2021). Ticks act as vectors for transmission of various diseases including the zoonotic diseases to both the humans and animals. These include bacterial, viral, protozoal and nematode infections collectively referred as tick-borne diseases (Sonenshine and Roe 2014). Both the increased tick prevalence and the rise in magnitude of tick-borne zoonotic diseases are of great concern with life-threatening potential in humans and animals (Cerny et al. 2020; Hromníková et al. 2022; Johnson et al. 2022).

Life Cycle of Ticks

Before we go into the detail of the impact that climate change exerts on ticks and the ticks-borne zoonotic diseases, there is a need for in-depth understanding of tick life cycle. Ticks are the blood sucking ectoparasites of vertebrates which have main four developmental stages, namely eggs, larva, nymph and adult, in their life cycle (Montales et al. 2016). The larvae hatch from eggs, feed on hosts and drop off on the ground where they develop into nymphs. These nymphs again find hosts, feed and again drop off where they undergo final molting into adults. These adults again attach to the hosts where they mate and the female drops off for eggs laying on the ground (Naseer et al. 2021). From the life cycle, it's very clear that most of the ticks' life span is spent in the open environment and are found attached to their hosts only when feeding is required (Dantas-Torres 2010; Estrada-Peña et al. 2012; Cunze et al. 2022). For survival in the open environment, they require certain climatic conditions like high humidity and rainfall to avoid desiccation and a suitable photoperiod and sunshine for proper molting (Belozerov 1982; Estrada-Peña et al. 2013; Gray et al. 2016; Ogden et al. 2021). Thus, any change in climatic conditions directly affects the ticks survival.

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Impact of Climate Change on Ticks

As described earlier, ticks rely on complex set of biotic and abiotic factors for their survival. However, climate is the key factor that determines the prevalence of ticks in a specific area and alters the tick-host-pathogen interactions, thus, opening new areas for ticks invasiveness and pathogenic transmission (Estrada-Peña et al. 2012). Climate change affects the ticks both by direct and indirect means via affecting their survival, reproduction, activity, habitat and their hosts (Ogden et al. 2021). The major impacts of climate change on ticks are discussed below:

Direct Effects

Changes in Geographical Distribution

Climate change has a strong influence over the quality of habitat and hosts abundance for ticks (Simon et al. 2014; Li et al. 2019). It may be either beneficial to the tick growth or may adversely affect the ticks. However, in the last few decades, there has been observed a continuous expansion in ticks geographical distribution even towards higher altitudes (Gray et al. 2009; Jaenson et al. 2012; Leger et al. 2013; Medlock et al. 2013). This is because of increased environmental temperatures along with changes in rainfall patterns which have enabled the ticks to establish new extended areas of their prevalence (Dautel et al. 2008; Keesing et al. 2018). This can be explained with the example of *Ixodes ricinus* tick whose spatial distribution has extended to areas in Europe where it was not recorded previously (Cunze et al. 2022). Furthermore, these climatic changes also favour exotic species in establishing themselves in new areas like an Asian native tick *Haemaphysalis longicornis* is now prevalent in America (Raghavan et al. 2019; Nuttall 2021). Moreover, there are predictions of tremendous increase in global distribution of ticks and inter-continental translocations (López González et al. 2021; Hornok et al. 2022).

Effect on Tick Seasonality, Phenology and Climatic Adaptation

Ticks have a specific pattern of their seasonal activity depending on the weather conditions which favour their host seeking behaviour. These weather conditions include ambient temperature, relative humidity, light intensity and photoperiod (Waladde and Rice 1982; Belozerov et al. 2002; Ostfeld and Brunner 2015; Heath 2021). Warm climate causes an advancement both in the resumption of activity in diapaused ticks as well as the eggs hatching, thus, influencing tick phenology. Over a 19 years period in New York, in the warmer years, *Ixodes scapularis* ticks phenology has been shown to advance by 3 weeks compared to the colder years (Levi et al. 2015). The tick activity of temperate areas is also on rise due to climate warming (Moore et al. 2014; Monaghan et al. 2015). This seasonal effect is more pronounced in the ticks having exophilic behaviour (Estrada-Peña et al. 2012; Ogden et al. 2021). This seasonal effect is evident from the fact that, in Brazil, *Rhipicephalus microplus* tick spends a constant duration of almost 21-23 days on the host irrespective of the season but off the host, this duration is 40-50 days in summer and spring while 70-120 days in winter and autumn (Cruz et al. 2020). Moreover, ticks of the same species have an ability of adaptation to different climatic conditions. This adaptation can be seen in questing behaviour among different populations of same tick species in different areas. Ticks are able to adapt to different climates because of the adaptive evolution and the altered gene expressions in ticks' sensory systems (Simo et al. 2014).

Effect on Tick Reproduction and Development

Climate change is believed to positively affect the ticks' reproduction and development. This positive effect can be seen in terms of increased abundance of ticks in a specific area. This is proved in a study in Russia where an increased abundance of *Ixodes ricinus* ticks was observed over the last 35 years with a 5°C increase in autumn and late summer temperatures (Korotkov et al. 2015). This shows temperature to be the most critical factor for ticks reproduction and development. It affects all the stages of ticks starting from egg laying to questing adults. It has an inverse relation with the duration of ticks development, i.e., the duration is shorter if the temperature is high and vice versa. Thus, the warming earth's climate leads to shortening of ticks life cycle (Ogden et al. 2021). For example, *Ixodes scapularis* tick in Canada takes 3-4 years for completion of its one generation cycle compared to 2 years in USA. Moreover, ticks exhibit behavioural and developmental diapause mechanisms to avoid fatal environmental conditions. Climatic temperature, as the main factor, modulates these mechanisms and as the conditions become favourable, these ticks resume their activity (Ludwig et al. 2016).

Indirect Effects

Effect on Susceptible Hosts

Ticks abundance in a specific area has a strong co-relation with their hosts availability. Any change in the hosts population directly affects the ticks ecology and evolution. These hosts are necessary for the completion of reproduction cycle in ticks (Gilbert 2010; Estrada-Peña et al. 2020). Ticks get their blood meal and, in turn, cause anaemia, weight loss, secondary infections and behavioural modifications in these hosts (Leger et al. 2013). These negative effects of ticks affect the breeding performance and survival of their hosts, thus, leading to alterations in host population dynamics. Moreover, when new tick species invade a new area due to the climate change, there occur several interactional changes in the community. As a result, some hosts may be favoured while others may be exploited (Tompkins et al. 2011). For example, *Rhipicephalus* (*R.*) *microplus* ticks are specifically the cattle ticks. But New Caledonia invasion by *R. microplus ticks* in 1942 lead to adaptation of rusa deer as their hosts. Initially regarded as poor host, it took almost 250 generations by *R. microplus* ticks to fully adapt to this host and are now existent as separate independent cattle and deer adapted populations (Barré et al. 2001; De Meeûs et al. 2010). This kind of adaptation is the key mechanism which helps ticks in their survival in the changing climate and maintain their biodiversity (Magalhães et al. 2007).

Impact of Climate Change on Ticks-borne Zoonotic Diseases

All the bacterial, viral or parasitic diseases which are transmitted from animals to humans are referred as the zoonotic diseases (Sonenshine 2018). Of all the infectious diseases, 60% are zoonotic in nature (Jones et al. 2008). Transmission of these diseases occurs through different routes like direct contact, inhalation and ingestion or may be vectored by arthropods (Kulkarni et al. 2015). Among the arthropods, ticks transmit the largest number of zoonotic diseases than any other arthropod (Durden 2006). According to CDC in USA, annually 95% of the 50000 notifiable locally acquired vector-borne diseases are tick-borne (Adams et al. 2016; Paddock et al. 2016). These ticks-borne zoonotic diseases are of great public health importance with an increasing worldwide incidence. This increasing diseases' incidence is attributed to the climate change which has direct influence over ticks abundance and survival, host availability and pathogens transmission (Dumic and Severnini 2018). Some of the ticks-borne zoonotic diseases include Lyme disease, tick-borne encephalitis, Crimean-Congo Hemorrhagic Fever, rickettsioses and tularemia (Fritz 2009). These diseases are directly related to ticks for their transmission. Thus, any climate change which affects the ticks either directly or indirectly would certainly have an impact on these ticks borne diseases (Ghafar et al. 2021).

Lyme Disease

Lyme disease or sometimes referred as Borreliosis is a bacterial disease caused mainly by *Borrelia burgdorferi*. It is a zoonotic disease transmitted through bite of infected *Ixodes* spp. ticks (Mills et al. 2010). As described earlier, these ticks pass through three developmental stages and complete their life cycle in 2-3 years depending on the climatic conditions. The climatic conditions resulting from global climate change have resulted in higher ticks prevalence through increased tick survival and host availability (Dumic and Severnini 2018). As a result, Lyme disease cases are increasing across the world. For example, in Canada in 2004, only 40 cases of Lyme disease were reported. During 2009 to 2015, these cases rose from 144 to 917 showing a six-fold increase (Koffi and Gasmi 2019). This increased incidence of the disease in Canada was linked to the northward geographical expansion of *Ixodes scapularis* ticks (Koffi and Gasmi 2019). These ticks rely on white-footed mouse as their primary hosts. Thus, the increased abundance of white-footed mouse favoured by climate change resulted in increased prevalence of *Ixodes* ticks ultimately leading to increased cases of Lyme disease (Mills et al. 2010; Roy-Dufresne et al. 2013). Similarly, the case data over the period of years 2000-2017 in USA indicated an increased incidence of Lyme disease in association with elevated annual climatic temperatures. This climate-disease association was most prominent in the northeast of USA (Couper et al. 2021). In the northeast, there was observed an association between the ticks, rodents and the climate change (Ogden et al. 2018). If this scenario continues in the USA, there is a prediction of 20% increase in Lyme disease incidence in the coming years (Dumic and Severnini 2018).

Tick-borne Encephalitis

It is a viral disease caused by tick-borne encephalitis virus of the *Flavivirus* genus. It is zoonotic in nature with humans acting as accidental hosts while small mammals as the main reservoirs. It affects the central nervous system of the humans and is distributed in Europe, Caucasus, Kazakhstan, Russia and China (Nah et al. 2020; Rubel 2021). In the past few decades, there has been observed a continuous rise in tick-borne encephalitis cases across the globe. It has been recorded even in those areas where it was previously absent (Daniel et al. 2018; Riccardi et al. 2019).

It is typically a seasonal disease linked to *Ixodes ricinus* ticks and particularly their nymphs. The disease transmission between ticks and hosts occurs through different routes like systemic, non-systemic and transovarial methods. In the systemic method, the transmission occurs in a cycle where the infected ticks bite the hosts and transmit pathogens to them. Then, the non-infected ticks bite the infected hosts and take up pathogens with the blood meal and transmit these pathogens to other non-infected hosts while feeding on them, thus, the systemic cycle continues so on. In the non-systemic method, the transmission occurs between infected and non-infected ticks through co-feeding on the same host before the pathogen has established itself in the host for systemic transmission. In the third transovarial method, the pathogens are transmitted from the infected females to the next generation through their eggs (Nah et al. 2019).

Among the various factors that influence the transmission of tick-borne encephalitis, climate change is the most important one. It directly affects the ticks' survival and movement, their reproduction and their ecological interactions (Wondim et al. 2022). The climate change leads to sustained tick-borne encephalitis disease transmission through increased host availability, increased tick abundance and extended periods of questing which allow co-occurrence of infected and non-infected nymphs and larvae (Nah et al. 2020).

Crimean-Congo Hemorrhagic Fever

It is also a tick-borne zoonotic disease caused by Crimean-Congo hemorrhagic fever virus of the family Nairoviridae. It transmits to humans mainly through the bite of infected *Hyalomma* ticks and is prevalent across Africa, Asia and Europe. Apart from tick biting, this disease can also spread through direct contact with the infected blood and body fluids of patients. Hence, due to its potential threat, it resides in the WHO's list of top eight emerging pathogens and categorized as level 4 biosecurity risk pathogen by CDC (Monsalve-Arteaga et al. 2020; Kuehnert et al. 2021).

As the global prevalence of Crimean-Congo Hemorrhagic Fever is concerned, it is constantly on the rise. There are reports of epidemics in the East Mediterranean countries for the last two decades (Portillo et al. 2021). It has even established itself in the regions where it was previously non-endemic like Turkey, Greece, Iran, India, Georgia and Spain etc. Moreover, apart from geographical expansion, it also possesses a higher incidence rate. For example, since the identification of first human case in 2002 in Turkey, the number grew to over 6300 in 2012. Similarly, huge increase in human cases had also been observed in Iran since the discovery of infection in 1999 (Bente et al. 2013).

The incidence and alterations in geographical ranges of this disease have a triad link with ticks and climatic conditions. Ticks harbour the pathogens and are dependent on climatic conditions for their survival and reproduction. As the conditions become favourable to the tick vectors due to climate change, the tick population grows in number and may establish itself in new geographical areas. As a result, the disease is introduced in new areas and an increase in tick bites occur which ultimately lead to increased pathogenic transmissions (Chinikar et al. 2010; Ahmed et al. 2021).

Conclusion

Climate change is an international issue which is having socioeconomic as well as political impacts. It poses a significant threat to the viability of ecosystem. It is leading towards global warming and irregular weather patterns which affect the biodiversity and cause geographical alterations in the species' habitats. Likewise, ticks are also affected by these changes as they are directly dependent on climatic factors like temperature, humidity, and vegetation coverage for their survival in the environment. Moreover, the host availability to ticks in specific geographical areas is also influenced by the climate change. In the last few decades, the climate change is seen to have favoured the ticks growth. There is seen an increased abundance and prevalence of ticks beyond their normal known geographical boundaries and, hence, an increased magnitude of ticks-borne zoonotic diseases.

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