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Impact of climate change on the mosquito vector

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Abstract

During the last few decades, average surface temperature of the Earth was increased by approximately 0.2°C/decades. Higher concentration of the green house gases leads to increase in atmospheric and Earth surface temperatures and cause global warming. Global warming can impact the physical as well as biological systems. Therefore, climate change may play a key role in transmission of several vectors borne disease. In the last thirty years, several new infectious diseases have been emerged in the world. Development, survival of mosquitoes and the dissemination of pathogens, all are controlled by the climatic factors. Climate change and unstable climatic condition may affect vector borne diseases. At present, impacts of climate change on mosquito life cycle and transmission of mosquito borne diseases is a serious issue. Temperature change affect pathogen development within the mosquitoes, mosquito survival and therefore vectorial capacity. In addition, precipitation in an area control the number of breeding sites for mosquitoes that have aquatic immature stages. It has been estimated that these diseases represent 17% of the global disease burden. These diseases are the major cause of mortality in several tropical and subtropical countries. Migration of malaria vectors from their conventional locations to invade the new geographical region is a matter of great concern. To prevent the vector borne diseases, continuous monitoring of mosquito population and mosquito transmitted diseases in the context of climate change is required. Furthermore, it seems essential to improve our knowledge based on the availability of present information and problems regarding mosquito surveillance and mosquito-borne infectious diseases.

Keywords: Mosquito, Geographical region, Climate, Vector

Introduction

During the last few decades, Earth's surface temperature has increased by about 0.2°C/decades (Hansen et al 2006). It has been estimated that by the end of the 21st century, the mean temperature of the Earth's surface will increase by approximately 1–3.5°C (Githeko *et al*. 2000). Uncontrolled human activities like burning of fossil fuels, deforestation, and industrial setup are the major source of greenhouse gases particularly, CO2, methane (CH4), nitrous oxide (N2O). Higher concentration of these gases increases atmospheric and Earth surface temperatures and cause global warming (Githeko *et al*. 2000, Karl and Trenberth 2003). Global warming can impact the physical and biological systems (Rosenzweig, *et al*. 2007). Therefore, climate change may play a key role in the transmission of several vectors borne diseases (Campbell-Lendrum *et al*. 2015). During the last few decades, several new infectious diseases have emerged in the world (Epstein *et al*. 1998). Resurgence of mosquito vectors and the redistribution of infectious diseases such as malaria and dengue fever have occurred worldwide (Epstein *et al*. 1998). Development, survival of mosquitoes and the dissemination of pathogens, all are controlled by climatic factors. Climate change and unstable climatic condition may affect vector borne diseases (Caminade *et al.* 2019). Mosquitoes are poikilothermic animal and fluctuating temperatures alter the development, reproduction and behaviour of mosquitoes (Lahondère and Bonizzoni, 2022). At present, the impacts of climate change on the mosquito life cycle and transmission of mosquito borne diseases is a serious issue. There is very little information regarding the influence of climate factors, such as temperature, rainfall and humidity on mosquito-borne diseases. Temperature change affects pathogen development within the mosquitoes, mosquito survival and therefore vectorial capacity (Liu *et al.* 2023). In addition, precipitation in an area controls the number of breeding sites for mosquitoes that have aquatic immature stages (Asgarian et al 2021). It has been estimated that these diseases represent 17% of the global disease burden (Karunamoorthi and Sabesan, 2013).. These diseases are the major cause of mortality in several tropical and subtropical countries.

Recent evidence shows that variation in temperature and precipitation alter the distribution and behaviour of the mosquito vector (Lamy *et al.* 2023). Migration of malaria vectors (Anopheles mosquitoes) from their conventional locations to invade the new geographical region is a matter of great concern (Tonnang *et al.* 2010). A small increase in temperature leads to an increase in the mosquito's development rate and the adult frequency of blood feeding (Costanzo and Occhino, 2023). To prevent vector-borne diseases, continuous monitoring of mosquito populations and mosquito-transmitted diseases in the context of climate change is required.

This review focuses on the influence of climate change on the mosquito vector and identifies the gaps in our knowledge. The objective of this chapter is to analyse: (i) the impacts of global warming on the development of mosquitoes; (ii) the effect of global warming on insecticide resistance.

Anopheles

The Anopheles mosquito is considered as primary malaria vector. It prefers mammals, including humans, for its blood meal (Feng *et al.* 2017). Hibernating females survive the winter season by resting in a cave (Sauer *et al.* 2022). While at high temperatures, adult anopheline mosquitoes find a micro habitat for their survival e.g. *Anopheles stephensi* shelters in water tanks in Rajasthan to deal with the higher temperatures (WHO 2008). Mosquito vectors such as *Anopheles minimus* search for outdoor locations in dense vegetation under adverse climatic conditions (Dhiman et al 2008). Eggs can resist the cold temperatures. The female Anopheles mates several times in her short lifespan and lay eggs after the blood meal (Ebrahimi *et al.* 2014). The female mosquito can lay up to 200 eggs individually over the water surface. For effective malaria transmission, a mosquito species needs to survive long enough after blood feeding to transfer the plasmodium species to a human being (Shaw *et al.* 2020). It allows the parasite to develop and travel to the mosquito's salivary glands ready to infect the next person bitten.

Aedes

In the last two decades, *Aedes* mosquitoes, the Asian tiger mosquito have conquered newer geographical regions quickly (Benedict *et al.* 2007). *Aedes albopictus can* breed in natural as well as artificial water filled container therefore they are labeled as container-breeder (Ferdousi *et al*. 2015). Its ability to breed in containers makes it associated with urban environments where water-storage tanks, tires and bottles, are easily available (Fansiri *et al.* 2021). Furthermore, its nature to feed on a wide range of species increases its potential as a vector (Egid *et al.* 2022). *Aedes albopictus* is a potent biter and diurnal feeding nature enhances their vectorial capability (Costanzo and Occhino, 2023). Diapausing eggs of *Ae. albopictus* populations in temperate zones permit overwinter the *Aedes Albopictus* population (Mogi *et al.* 2014). Consequently, *Aedes albopictus* has an extensive geographical distribution than *Aedes aegypti*, which spans tropical, subtropical, and temperate habitats and enhances the possibility of disease transmission in temperate regions of the world (Zhang *et al.* 2022).

Another species of Aedes mosquito is *Aedes aegypti*. It is well established throughout the tropical and subtropical regions of the world. Eggs can survive several months in harsh environmental conditions. It facilitates the dispersal and survival during dry periods (Ebi and Nealon, 2016). *Aedes aegypti* origin is connected to Africa and thereafter transported to the America through slave trade (Kotsakiozi *et al.* 2018). The female predominantly feeds on human beings, and the ability to take multiple blood meals/gonotrophic cycle (Norris *et al.* 2010) increases its vectorial capacity. The geographic distribution is controlled by cold temperatures. *Aedes aegypti* did not survive below 10°C, proven to be the climatic boundary for survival **(**Reinhold *et al.* 2018**)**.

Culex

Culex mosquito are vector of great concern. *Culex* species has been identified as the primary vector of West Nile Virus (Moser *et al.* 2023). *Cules quinquefasciatus* resides in the tropical and subtropical regions of the world whereas *Culex pipiens* mainly found in temperate zone. Unlike *Culex pipiens, Culex quinquefasciatus* are not capable of diapause, it limited the distribution iof *Culex quinquefasciatus (*Moser *et al.* 2023). *Culex quinquefasciatus* a primary vector of the filarial worm, *Wuchereria bancrofti* in Brazil (Brito *et al.* 1997), tropical Africa, and Southeast Asia (Samy et al 2016). Recently, researchers have raised the concern over possibility of *Culex quinquefasciatus* involvement in the transmission of Zika virus (ZIKV) in Brazil. *Culex quinquefasciatus* numbers in Brazil are approximately 20 times higher than the *Aedes aegypti* (Melo *et al.* 2016).

Effects of climate factors on vectors and parasites

Environmental conditions have been associated with significant variation in both adult and immature stage characteristics of insects, including larval growth rates, development times, body size, fecundity, and longevity (Ciota *et al.* 2014). Insect physiology works optimally within a lean range of temperatures, and shifting from this range may impact the developmental cycle (Mpho *et al*. 2002). Furthermore, there is a relationship between development time and insects size and fitness. Slightly shift from their comfort range can affect their survival, feeding, and fecundity in negative manner (Mohammed and Chadee, 2011). Alterations in life history characteristics lead to the considerable change in the vectorial capacity of mosquitoes (Delatte *et al*. 2009).
Higher temperatures often lead to increased precipitation and amount of rainfall. Higher rainfall increases the vector population and disease transmission by providing more breeding spaces for vectors like mosquitoes (Gage *et al.* 2008). However, not all conditions of rainfall favor mosquito's survival and reproduction. Flooding has negative effects on the density of their population because it can destroy the breeding sites as well as the eggs and larvae of mosquitoes (Chang *et al.* 2014). Increasing temperature provides higher transmission potential to vectors, shortens the generation time, population growth rate of vector increase and decreases incubation periods (Tidman *et al.* 2021, Suh *et al.* 2024).

Likewise, increased rainfall conditions also increase transmission potential, habitats of vector larval stage and population sizes (Ahmed *et al.* 2019). Exposure to high temperatures confers serious physiological changes in ectothermic animals (Dingha *et al.* 2009). Aquatic larval stages of insects are easily influenced by temperature changes attributed to the thermal conductivity of water and the restricted escaping ability of the larval stages. For example, *Anopheles* arabiensis larval development rate tends to increase as temperature increases (Agyekum *et al.* 2021). Generally, increased temperatures stimulated the development rate of parasites (Martens *et al*. 1995). Extreme heat could be lethal for mosquitoes, but within certain ranges, mosquitoes can survive. In this range blood sucking activity of mosquito increase (Agyekum *et al.* 2021).

The minimum temperature for the development of *Plasmodium vivax* inside the anopheles species is 14.5–16.5 °C, whereas for *Plasmodium falciparum* minimum temperature ranges from 16.5–19°C (Macdonald 1957, Martens *et al.* 1995). Furthermore, the optimum temperature for the development of the malaria parasite is 20–30 °C temperature (Bruce-Chwatt, 1971). Sporogony of *Plasmodium vivax is c*ompleted in 55 days at 16 °C whereas at 28 °C, the process completed within seven days (WHO, 1995).

The pathogen development time is shortened and therefore, the maturity rate increases (MacArthu,r 1972; Epstein, 2001). For example, *Anopheles* mosquitoes, which carry malarian parasites, the increased temperatures allow malarian protozoans to mature quickly so that the mosquito's efficiency to transmit the disease would increase (Kripa *et al.* 2024).

Exaggerated temperature stretches the geographic distribution of mosquito vector. Transmission of Plasmodium falciparum by *Anopheles* mosquitoes starts when environmental temperatures cross 16°C (Mordecai *et al*. 2013). *Aedes aegypti*, can not survive below the 10°C. Eggs, larvae and adult stages of Aedes species are unable to deal with the cold temperature. Temperatures above 10°C are essential for the reproduction and disease transmission by *Aedes* species (Reinhold *et al.* 2018, Epstein, 2001). Warmer environmental conditions promote mosquitoes and mosquito-borne diseases, which will certainly affect human health. Higher global temperatures increase the disease transmission rates and also expand the geographic ranges.

Insecticide resistance

The development of insecticide resistance in mosquitoes is a nuisance for malaria control and its elimination programs. Understanding of resistance mechanisms in mosquito vectors enables the development of resistance management strategies. The significance of temperature in insecticide resistance cannot be denied. Environmental temperature can alter the mosquito's physiology as well as enzyme function. It influences the rates of cuticle penetration, interaction of insecticide to its target-site and detoxifying enzyme activity. When toxicity of insecticides increases with temperatures called as positive temperature coefficient; whereas when toxicity decreases with temperatures known as the negative temperature coefficient. Temperature coefficients vary according to insecticides and species (Khan and Akram, 2014).

Patil et al. (1996) induced cross-tolerance in anopheline larvae by exposing them to elevated temperatures. Elevated temperatures increased the level of pyrethroid resistance in *Culex quinquefasciatus* (Swain *et al*. 2009). On the contrary, Whiten and Peterson (2016) reported a negative temperature coefficient for permethrin in *Aedes aegypti*. Higher temperature is responsible for improved α-esterase activity in *Culex Quinquefasciatus* (Swain *et al*. 2009) and *Aedes aegypti*. (Polson *et al*. 2012). β-esterase activity result was not consistent in comparison to α-esterase activity, in *Culex quinquefasciatus* β-esterase was suppressed (Swain *et al*. 2009) while enhanced activity was reported in *Aedes aegypti* (Polson *et al*. 2012). Furthermore, study with *Anopheles stephensi* (Hadaway and Barlow, 1963) and *Aedes aegypti* (Polson *et al*. 2012) revealed that organophosphate killed more mosquitoes at higher temperatures, while DDT susceptibility decreased as temperature 200 increased from 20°C to 30°C (Hadaway and Barlow, 1963). According to Oliver and Brooke (2017), in *Anopheles arabiensis,* heat shock reduces pyrethroid susceptibility in the insecticide-resistant rather than susceptible, *An. arabiensis.* They urge that the induction of heat shock proteins played a role in heat shock-induced pyrethroid resistance augmentation. However, in case malathion they reported that neither the elevated rearing temperature nor the short-term heat shock had affected the malathion resistance phenotype.

Vector Control Challenges and Perspectives

Understanding the role of climate change on infectious disease is highly valuable. Long-term disease control strategies require extensive longitudinal surveillance systems capable of detecting (and dealing with) distribution patterns, ecological preferences, and behavioral trends of important vector species, which could significantly improve our ability to understand these transmission pattern and it could be useful for us to predict and employ the most appropriate vector control strategy shortly.

The present vector-borne disease control methods are inadequate to deal with the negative outcome of global warming. In recent decades, the sudden global economic development, climate change with increased urbanization have considerably changed the disease transmission pattern.

Strategies for mosquito control

Rather than depending on a single strategy, mosquito control programmes must focus on the integrated approach. The integrate approach involves surveillance of mosquitoes to track the number and types of mosquitoes in a particular area. Public awareness and destruction of breeding sites, like stagnant water pools, water filled pots and clean environments are the best preventive measures to control mosquitoes. Destruction of vector breeding sites is an effective and economical tool for mosquito control.

Natural enemies and mosquito parasites are environment friendly control measures. In recent years, the sterile insect technique has been a species specific control method for mosquitoes. The use of mechanical traps is another nontoxic method for controlling the number of mosquitoes. Pesticide use in mosquito control has hazardous effects that often outweigh any possible benefits; the pesticide use strategy must, therefore, be used only as a last resort alternative. Therefore "Integrated Mosquito Management" method can effectively address sustainable mosquito control programs.

Since mosquitoes can breed in a small water filled space it is necessary to target mosquito breeding sites to reduce mosquito populations. All water-filled containers must be removed and drained, ditches, and water pits must be eliminated. Areas may need filling with soil. If it is not possible to drain or fill the problem areas with soil, the water source should be made unusable by mosquitoes. Poorly-drained water resources support the development of vegetation and become prime areas for the laying of eggs and larval development of mosquitoes.

References:-

1. Agyekum, T. P., Botwe, P. K., Arko-Mensah, J., Issah, I., Acquah, A. A., Hogarh, J. N., ... & Fobil, J. N. (2021). A systematic review of the effects of temperature on Anopheles mosquito development and survival: implications for malaria control in a future warmer climate. *International journal of environmental research and public health*, *18*(14), 7255.
2. Ahmed, T., Hyder, M. Z., Liaqat, I., & Scholz, M. (2019). Climatic conditions: conventional and nanotechnology-based methods for the control of mosquito vectors causing human health issues. *International journal of environmental research and public health*, *16*(17), 3165.
3. Asgarian, T. S., Moosa-Kazemi, S. H., & Sedaghat, M. M. (2021). Impact of meteorological parameters on mosquito population abundance and distribution in a former malaria endemic area, central Iran. *Heliyon*, *7*(12).
4. Benedict, M. Q., Levine, R. S., Hawley, W. A., & Lounibos, L. P. (2007). Spread of the tiger: global risk of invasion by the mosquito Aedes albopictus. *Vector-borne and zoonotic Diseases*, *7*(1), 76-85
5. Brito, A. C., Williams, P., Fontes, G., & Rocha, E. M. (1997). A comparison of two Brazilian populations of Culex quinquefasciatus (Say, 1823) from endemic and non-endemic areas to infection with Wuchereria bancrofti (Cobbold, 1877). *Memórias do Instituto Oswaldo Cruz*, *92*, 33-36.

6. Bruce-Chwatt, L. J. (1971). Epidemiology of malaria. *British Medical Journal*, *4*(5780), 170.
7. Caminade, C., McIntyre, K. M., & Jones, A. E. (2019). Impact of recent and future climate change on vector-borne diseases. *Annals of the New York Academy of Sciences*, *1436*(1), 157-173.
8. Campbell-Lendrum, D., Manga, L., Bagayoko, M., & Sommerfeld, J. (2015). Climate change and vector-borne diseases: what are the implications for public health research and policy?. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1665), 20130552.
9. Chang, A. Y., Fuller, D. O., Carrasquillo, O., & Beier, J. C. (2014). Social justice, climate change, and dengue. *Health & Hum. Rts. J.*, *16*, 93.
10. Ciota, A. T., Matacchiero, A. C., Kilpatrick, A. M., & Kramer, L. D. (2014). The effect of temperature on life history traits of Culex mosquitoes. *Journal of medical entomology*, *51*(1), 55-62.
11. Costanzo, K., & Occhino, D. (2023). Effects of temperature on blood feeding and activity levels in the tiger mosquito, Aedes albopictus. *Insects*, *14*(9), 752.
12. Delatte, H., Gimonneau, G., Triboire, A., & Fontenille, D. (2009). Influence of temperature on immature development, survival, longevity, fecundity, and gonotrophic cycles of Aedes albopictus, vector of chikungunya and dengue in the Indian Ocean. *Journal of medical entomology*, *46*(1), 33-41.
13. Dhiman, R. C., Pahwa, S., & Dash, A. P. (2008). Climate change and malaria in India: Interplay between temperature and mosquitoes. In *Regional Health Forum* (Vol. 12, No. 1, pp. 27-31). New Delhi, India: World Health Organization South-East Asia Region.
14. Dingha, B. N., Appel, A. G., & Vogt, J. T. (2009). Effects of temperature on the metabolic rates of insecticide resistant and susceptible German cockroaches, Blattella germanica (L.)(Dictyoptera: Blattellidae). *Midsouth Entomologist*, *2*, 17-27.
15. Ebi, K. L., & Nealon, J. (2016). Dengue in a changing climate. *Environmental research*, *151*, 115-123.
16. Ebrahimi, B., Shakibi, S., & Foster, W. A. (2014). Delayed egg hatching of Anopheles gambiae (Diptera: Culicidae) pending water agitation. *Journal of Medical Entomology*, *51*(3), 580-590.
17. Egid, B. R., Coulibaly, M., Dadzie, S. K., Kamgang, B., McCall, P. J., Sedda, L., ... & Wilson, A. L. (2022). Review of the ecology and behaviour of Aedes aegypti and Aedes albopictus in Western Africa and implications for vector control. *Current research in parasitology & vector-borne diseases*, *2*, 100074.
18. Epstein, P. R., Diaz, H. F., Elias, S., Grabherr, G., Graham, N. E., Martens, W. J., ... & Susskind, J. (1998). Biological and physical signs of climate change: focus on mosquito-borne diseases. *Bulletin of the American Meteorological Society*, *79*(3), 409-418.
19. Epstein, P. R. (2001). Climate change and emerging infectious diseases. *Microbes and infection*, *3*(9), 747-754.
20. Fansiri, T., Buddhari, D., Pathawong, N., Pongsiri, A., Klungthong, C., Iamsirithaworn, S., ... & Ponlawat, A. (2021). Entomological risk assessment for dengue virus transmission during 2016–2020 in Kamphaeng Phet, Thailand. *Pathogens*, *10*(10), 1234.
21. Feng, X., Zhang, S., Huang, F., Zhang, L., Feng, J., Xia, Z., ... & Zhou, S. (2017). Biology, bionomics and molecular biology of Anopheles sinensis Wiedemann 1828 (Diptera: Culicidae), main malaria vector in China. *Frontiers in Microbiology*, *8*, 1473.
22. Ferdousi, F., Yoshimatsu, S., Ma, E., Sohel, N., & Wagatsuma, Y. (2015). Identification of essential containers for Aedes larval breeding to control dengue in Dhaka, Bangladesh. *Tropical medicine and health*, *43*(4), 253-264.
23. Gage, K. L., Burkot, T. R., Eisen, R. J., & Hayes, E. B. (2008). Climate and vectorborne diseases. *American journal of preventive medicine*, *35*(5), 436-450.

24. Githeko, A. K., Lindsay, S. W., Confalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: a regional analysis. *Bulletin of the world health organization*, *78*(9), 1136-1147.

25. Hadaway, A. B., & Barlow, F. (1963). The influence of environmental conditions on the contact toxicity of some insecticide deposits to adult mosquitos, Anopheles stephensi List. *Bulletin of Entomological Research*, *54*(2), 329-344.

26. Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W., & Medina-Elizade, M. (2006). Global temperature change. *Proceedings of the National Academy of Sciences*, *103*(39), 14288-142

27. Karl, T. R., & Trenberth, K. E. (2003). Modern global climate change. *science*, *302*(5651), 1719-1723.

28. Karunamoorthi, K., & Sabesan, S. (2013). Insecticide resistance in insect vectors of disease with special reference to mosquitoes: a potential threat to global public health.

29. Khan, H. A. A., & Akram, W. (2014). The effect of temperature on the toxicity of insecticides against Musca domestica L.: implications for the effective management of diarrhea. *PloS one*, *9*(4), e95636.

30. Kotsakiozi, P., Evans, B. R., Gloria-Soria, A., Kamgang, B., Mayanja, M., Lutwama, J., ... & Powell, J. R. (2018). Population structure of a vector of human diseases: Aedes aegypti in its ancestral range, Africa. *Ecology and evolution*, *8*(16), 7835-7848.

31. Kripa, P. K., Thanzeen, P. S., Jaganathasamy, N., Ravishankaran, S., Anvikar, A. R., & Eapen, A. (2024). Impact of climate change on temperature variations and extrinsic incubation period of malaria parasites in Chennai, India: implications for its disease transmission potential. *Parasites & Vectors*, *17*(1), 134.

32. Lahondère, C., & Bonizzoni, M. (2022). Thermal biology of invasive Aedes mosquitoes in the context of climate change. *Current Opinion in Insect Science*, *51*, 100920.

33. Lamy, K., Tran, A., Portafaix, T., Leroux, M. D., & Baldet, T. (2023). Impact of regional climate change on the mosquito vector Aedes albopictus in a tropical island environment: La Réunion. *Science of the Total Environment*, *875*, 162484.

34. Liu, Z., Zhang, Q., Li, L., He, J., Guo, J., Wang, Z., ... & Li, T. (2023). The effect of temperature on dengue virus transmission by Aedes mosquitoes. *Frontiers in Cellular and Infection Microbiology*, *13*, 1242173.

35. Macdonald. G, M. G. (1957). The epidemiology and control of malaria.

36. Martens, W. J., Niessen, L. W., Rotmans, J., Jetten, T. H., & McMichael, A. J. (1995). Potential impact of global climate change on malaria risk. *Environmental health perspectives*, *103*(5), 458-464.

37. Melo, A. O., Malinger, G., Ximenes, R., Szejnfeld, P. O., Sampaio, S. A., & De Filippis, A. B. (2016). Zika virus intrauterine infection causes fetal brain abnormality and microcephaly: tip of the iceberg?. *Ultrasound in obstetrics & gynecology: the official journal of the International Society of Ultrasound in Obstetrics and Gynecology*, *47*(1), 6-7.

38. Mogi, M., Armbruster, P., & Fonseca, D. M. (2014). Analyses of the northern distributional limit of Aedes albopictus (Diptera: Culicidae) with a simple thermal index. *Journal of medical entomology*, *49*(6), 1233-1243.

39. Mohammed, A., & Chadee, D. D. (2011). Effects of different temperature regimens on the development of Aedes aegypti (L.)(Diptera: Culicidae) mosquitoes. *Acta tropica*, *119*(1), 38-43.

40. Mordecai, E. A., Paaijmans, K. P., Johnson, L. R., Balzer, C., Ben-Horin, T., de Moor, E., ... & Lafferty, K. D. (2013). Optimal temperature for malaria transmission is dramatically lower than previously predicted. *Ecology letters*, *16*(1), 22-30.
41. Moser, S. K., Barnard, M., Frantz, R. M., Spencer, J. A., Rodarte, K. A., Crooker, I. K., ... & Manore, C. A. (2023). Scoping review of Culex mosquito life history trait heterogeneity in response to temperature. *Parasites & Vectors*, *16*(1), 200.
42. Mpho M, Callaghan A, Holloway GJ. Temperature and genotypic effects on life history and fluctuating asymmetry in a field strain of Culex pipiens. Heredity (Edinb) 2002;88:307–312. doi: 10.1038/sj.hdy.6800045.
43. Norris, L. C., Fornadel, C. M., Hung, W. C., Pineda, F. J., & Norris, D. E. (2010). Frequency of multiple blood meals taken in a single gonotrophic cycle by Anopheles arabiensis mosquitoes in Macha, Zambia. *The American journal of tropical medicine and hygiene*, *83*(1), 33.
44. Oliver, S. V., & Brooke, B. D. (2017). The effect of elevated temperatures on the life history and insecticide resistance phenotype of the major malaria vector Anopheles arabiensis (Diptera: Culicidae). *Malaria journal*, *16*, 1-13.
45. Patil, N. S., Lole, K. S., & Deobagkar, D. N. (1996). Adaptive larval thermotolerance and induced cross-tolerance to propoxur insecticide in mosquitoes Anopheles stephensi and Aedes aegypti. *Medical and veterinary entomology*, *10*(3), 277-282.
46. Polson, K. A., Brogdon, W. G., Rawlins, S. C., & Chadee, D. D. (2012). Impact of environmental temperatures on resistance to organophosphate insecticides in Aedes aegypti from Trinidad. *Revista Panamericana de Salud Pública*, *32*, 1-8.
47. Reinhold, J. M., Lazzari, C. R., & Lahondère, C. (2018). Effects of the environmental temperature on Aedes aegypti and Aedes albopictus mosquitoes: a review. *Insects*, *9*(4), 158.
48. Rosenzweig, C., Casassa, G., Karoly, D. J., Imeson, A., Liu, C., Menzel, A., ... & Parry, M. L. (2007). Assessment of observed changes and responses in natural and managed systems.

49. Samy, A. M., Elaagip, A. H., Kenawy, M. A., Ayres, C. F., Peterson, A. T., & Soliman, D. E. (2016). Climate change influences on the global potential distribution of the mosquito Culex quinquefasciatus, vector of West Nile virus and lymphatic filariasis. *PloS one*, *11*(10), e0163863.
50. Sauer, F. G., Timmermann, E., Lange, U., Lühken, R., & Kiel, E. (2022). Effects of hibernation site, temperature, and humidity on the abundance and survival of overwintering Culex pipiens pipiens and Anopheles messeae (Diptera: Culicidae). *Journal of Medical Entomology*, *59*(6), 2013-2021.
51. Shaw, W. R., Holmdahl, I. E., Itoe, M. A., Werling, K., Marquette, M., Paton, D. G., ... & Catteruccia, F. (2020). Multiple blood feeding in mosquitoes shortens the Plasmodium falciparum incubation period and increases malaria transmission potential. *PLoS pathogens*, *16*(12), e1009131.
52. Shelton, R. M. (1973). The effect of temperatures on development of eight mosquito species.
53. Suh, E., Stopard, I. J., Lambert, B., Waite, J. L., Dennington, N. L., Churcher, T. S., & Thomas, M. B. (2024). Estimating the effects of temperature on transmission of the human malaria parasite, Plasmodium falciparum. *Nature Communications*, *15*(1), 3230.
54. Swain, V., Seth, R. K., Raghavendra, K., & Mohanty, S. S. (2009). Characterization of biochemical based insecticide resistance mechanism by thermal bioassay and the variation of esterase activity in Culex quinquefasciatus. *Parasitology research*, *104*, 1307-1313.

55. Tidman, R., Abela-Ridder, B., & de Castañeda, R. R. (2021). The impact of climate change on neglected tropical diseases: a systematic review. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, *115*(2), 147-168.
56. Tonnang, H. E., Kangalawe, R. Y., & Yanda, P. Z. (2010). Predicting and mapping malaria under climate change scenarios: the potential redistribution of malaria vectors in Africa. *Malaria journal*, *9*, 1-10.
57. Whiten, S. R., & Peterson, R. K. (2016). The influence of ambient temperature on the susceptibility of Aedes aegypti (Diptera: Culicidae) to the pyrethroid insecticide permethrin. *Journal of medical entomology*, *53*(1), 139-143.
58. World Health Organization. (1995). *Manual on practical entomology in malaria*. World Health Organization.
59. World Health Organization. (2008). *Regional Health Forum, Vol. 5, No. 2* (Vol. 5, No. 2). WHO Regional Office for South-East Asia.
60. Zhang, Q., Jiang, Y., Li, C., Gao, J., Zhao, T., Zhang, H., ... & Guo, X. (2022). Survival and Replication of Zika Virus in Diapause Eggs of Aedes Albopictus From Beijing, China. *Frontiers in Microbiology*, *13*, 924334.