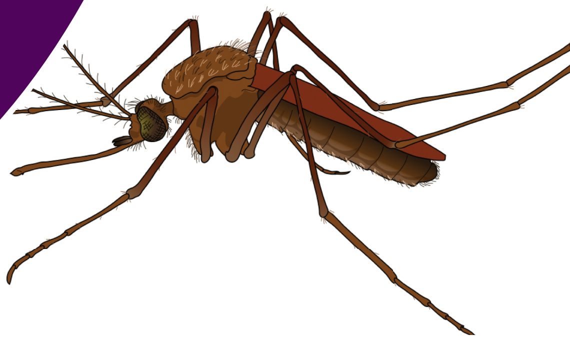
FEATURE ARTICLE

The Effect of Climate Change on Mosquito-Borne Diseases



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Abstract

Global climate change will affect all living things on this planet. For many species, the change in their environment may mean extinction. However, there is one organism, the mosquito, that may benefit from changes in the climate. This paper addresses the possible effects of climate change on mosquitoes, including longer breeding seasons and increased hatch rates of populations. The enlarged population will cause mosquitoes to seek more territory, and the warmer climate will in turn make more territory available. If mosquitoes increase in population, there may be an amplification of mosquito-borne diseases such as malaria, yellow fever, Chikungunya virus, St. Louis encephalitis, West Nile virus, and the Zika virus. This trend of increased range because of climate change has already been observed in dengue fever. This information can be used as an engaging segue into teaching students about climate change and vector-borne disease.

Key Words: *mosquitoes; vector-borne diseases; climate change; hatch rate.*

○ Introduction

The world has been experiencing unprecedented droughts, hurricanes, melting of the ice caps, and rising of the ocean levels, all effects of global climate change. Climate change is also seriously affecting the biotic world (Cornwall, 2016). Ocean warming and acidification are causing the bleaching of coral reefs (Hooidonk et al., 2014). Not only will reptiles' nesting sites be inundated with water, but one sex or the other may be influenced by the temperature of the sand (Fuentes et al., 2011).

A winner in the climate change challenge is the mosquito.

A winner in the climate change challenge is the mosquito. As the globe continues to warm, the range of disease-carrying mosquitoes will expand. Currently, areas that hard-freeze during the winter have fewer mosquitoes because the insects cannot breed during the winter. The overwintering areas become too cold, and the eggs are destroyed. As the climate warms, these areas could become year-round breeding grounds (Ewing et al., 2016).

For areas where mosquitoes breed year round, the increased temperature will allow them to breed faster. According to Alto and Juliano (2001), higher temperatures increase reproduction rates. If mosquitoes hatch at a quicker rate, their reproduction rate will increase exponentially (Semenza et al., 2012; Daniel et al., 2009). One can hypothesize that if mosquito hatch rate increases, the spread of vector-borne diseases will increase as well. A comprehensive 23-year study of province-specific dengue reports across nine climatic regions found that we have already witnessed an increase in dengue fever not only in number but also in range (Colon-Gonzalez et al., 2013). This increase is a concern because the vectors of dengue belong to the genus *Aedes*, a diurnal generalist that already enjoys a large range in the United States.

○ Review of Literature

Effects of Climate Change on Mosquitoes

Kovats and colleagues (2001) cite many studies that say climate change has already begun to affect organisms. Their study outlines the ramifications of climate change and how mosquitoes will be affected: (1) Developmental rates will increase, amplifying the hatch rate. (2) Mosquitoes' range will increase in both latitude and altitude. (3) The life-cycle timeline will increase, and mosquitoes will begin egg laying younger. (4) Mosquitoes will adapt with shorter generations and rapid growth rates. These four ramifications are already being witnessed.

Hatch Rate

In their experiment comparing 22°C, 24°C, and 26°C, Alto and Juliano (2001) found that not only hatch rate but also development rate significantly changed. They hypothesized that a temperature

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increase could enlarge the range for *Aedes albopictus* mosquito to all of North America. Earlier spring means earlier reproduction. Warmer summers will favor increased reproduction in adults. As a population, increasing *Aedes albopictus* will colonize new areas, and because of the warmer temperatures, more areas will be suitable for colonization.

Range

Alto and Juliano (2001) concluded that as the mosquito population increases, it *would* need to colonize new areas, and because of the warmer temperatures, more areas will be suitable for colonization. A study of the invasion of the Asian tiger mosquito, which first arrived in Houston, Texas, in 1985 hidden in tires, found that this mosquito increases its range using human-aided transport, whether vehicle or even a human vector. The study also concluded land use changes and climate change aided in this dispersal (Medley et al., 2015). Dengue fever, spread by the Asian tiger mosquito, has increased in geographic range as well as incidence in the last fifty years. Infection is now possible in 50 percent of the world population (Reiter, 2001; Yacoub et al., 2011). Lafferty (2009) stated the range of vector-borne disease would increase not only in latitude but also in altitude because climate change will expand the potential range of species that thrive in a warm habitat.

Metabolism

Warmer temperatures increase chemical reactions, thus increasing cell metabolism in mosquitoes (Lafferty, 2009). It has been documented that in warmer climates, adult females digest blood more quickly and feed more frequently, thereby producing more broods (Lee et al., 2013). Climate change also allows mosquitoes to emerge earlier and remain later in the season than previously observed. Some species may be able to survive during the winter months because the weather is not as cold. Temperature is a key component in developmental rates, immune response, frequency of feeding, and susceptibility to parasites (Sternberg & Thomas, 2014).

Evolution

Sternberg and Thomas (2014) suggest temperature could become a source of adaptive selection that could facilitate an expansion of vectors. Climate change may also affect the pathogens within the mosquitoes. Using history and experimental evidence, Lafferty (2009) found a relationship between climate change and disease pathogens. For example, McMichael (2010) demonstrated a direct relationship between recurrence of the Plague and warmer temperatures. These associations suggest that climate can affect infectious disease in a nonlinear fashion (Lafferty, 2009). Even small changes in seasons may increase the rate of spread exponentially when a new population encounters a disease for which it lacks immunity.

○ Mosquito-Borne Pathogens

Lee and colleagues (2013) agree that climate change affects not only survival rates of the vector but also development and transmission rates for the vector-borne diseases. This finding is consistent with the data for dengue virus and the mosquito that carries it. Higher temperatures shorten the incubation period for the virus as well as breeding and development of the mosquito, increasing dengue transmission (Colon-Gonzalez et al., 2013).

A study by Singh, Shukla, and Chandra (2005) added another variable to this complex issue, human population density. Simply put, as the mosquito population increases, mosquitoes will infect more humans. The more humans that are infected, the more chance mosquitoes have to become infected. In other words, the denser the human population, the more likely mosquito-borne pathogens will spread. These include the following deadly diseases.

Malaria

Malaria, a blood-borne pathogen *Plasmodium falciparum* transmitted by *Anopheles* mosquitoes, kills more people than any other disease in the world (Reiter, 2001). Malaria is endemic to poor, tropical countries (Ehiri et al., 2004). A study by Yacoub, Kotit, and Yacoub (2011) found that, of the over 247 million people infected with malaria in 2008, 1 million died. One-third of the world's population lives in an area where malaria can be found. Recent cases of malaria have been found in Europe; most have been traced to visitors to sub-Saharan Africa or immigrants fleeing war in an endemic area (Askling et al., 2012).

Dengue Fever

The most common viral disease in the world spread by mosquitoes is dengue fever. Research by Bouzid and colleagues (2014) demonstrated that warmer weather would extend the range of mosquitoes into previously unaffected areas.

Both *Aedes aegypti* and *A. albopictus* are now spreading dengue fever. *Aedes* is well adapted to urban settings, is diurnal, prefers peridomestic settings, and can reproduce in almost any container that holds water. This scenario is more likely in wealthier countries because *A. albopictus* prefers the urban garden setting, biting during the day (Lambrecht et al., 2010).

Four viruses cause dengue, and though very closely related, these four serotypes do not confer immunity for each other (Bambrick et al., 2009). Dengue has been called breakbone fever because it causes severe pain in the muscles, joints, and head. It also causes nausea, skin rash, and vomiting. Many people who are infected with more than one serotype may suffer from dengue hemorrhagic fever/dengue shock syndrome (DHF/DSS). Fatality for DHF/DSS is about 50 percent as the blood vessels become permeable and the patient bleeds out (Reiter, 2001).

The geographic range, as well as incidence, has increased in the last fifty years. Infection is now possible in 50 percent of the world population (Reiter, 2001; Yacoub et al., 2011). Figure 1 shows how dengue fever has increased over the last 65 years.

Yellow Fever

The tropical disease yellow fever came to the United States from Africa aboard slave ships in their water supply. Besides finding a new host, the disease infected at least 14 species of *Aedes* mosquitoes. The disease can be fatal (20 to 50 percent of the time), and other symptoms include high fever and spontaneous bleeding (Reiter, 2001).

A. aegypti is the most common vector and is associated with human habitation, and readily breeds in any container holding water. In the United States, its range currently extends as far north as North Carolina. As with the malaria parasite, higher temperatures cause the pathogen to reproduce more quickly (Martens et al., 1995).

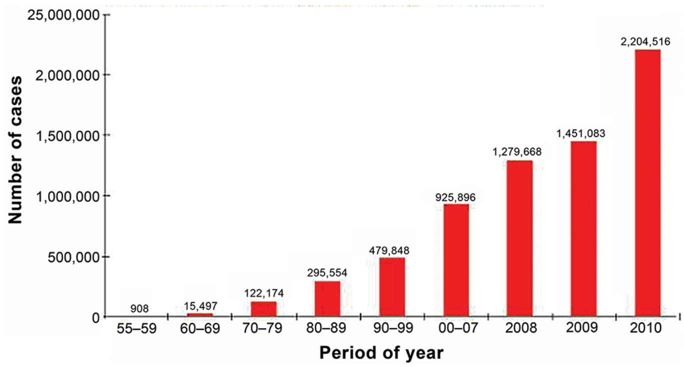

Figure 1. Cases of Dengue fever reported to WHO in the last 65 years (World Health Organization, 2012).

Chikungunya

Chikungunya, its name from an African dialect and meaning "that which bends up," was first recorded in Asia and Africa in 1779. However, because most all the victims were poor, little attention was paid until 2005, when Chikungunya invaded the French Island of Réunion. With this outbreak came epidemiological changes in the disease. The first change was a switch in its primary host from *Aedes aegypti* to *A. albopictus*. This is significant because *A. albopictus* has a very quick life cycle, is anthropophilic, and with climate change is rapidly spreading throughout the world. Increased virulence was the second change that transformed Chikungunya from an extremely painful but nonlethal disease to one that cripples and kills. New symptoms include kidney failure, thrombocytopenia (and subsequently, bleed outs), meningoencephalitis, and direct infection from mother to child. Of the recovered patients, 93.7 percent of them reported chronic arthritis leading to severe disability (Meason & Paterson, 2014).

West Nile Virus

According to Hahn and colleagues (2015), West Nile is the most ubiquitous mosquito-borne virus in the United States. It was first observed in 1999 in New York, quickly spread through the country, and reached the Pacific Coast by 2003. A study by Hahn et al. (2015) found a direct correlation between the number of cases and the climate. This study analyzed both the temperature and precipitation in each area of the country from 2004 through 2014. Interestingly, low precipitation was loosely correlated with a rise in West Nile, and an article by Meason and Paterson (2014) suggests that people are likely to save more water during a drought in places that would make great breeding spots for mosquitoes.

Counties in seven of ten regions in the United States that experienced higher than normal average temperature increases also experienced higher than normal cases of West Nile disease. The study also found that warmer winter temperature predicted a higher disease rate the following summer (Hahn et al., 2015). A higher infection rate agreed with earlier research by Wimberly, Lamsal, Giacomo and Chuang (2014) that found warmer spring and summer caused accelerated larval emergence, development, and mating, increasing the abundance of mosquitoes. A higher temperature also accelerates viral replication.

Zika Virus

The latest virus to use mosquitoes as a vector is Zika. Currently, the fallout from this disease links Guillain-Barré Syndrome (GBS), microcephaly, and possibly blindness (CDC, 2016c). The virus is named after the Zika Forest of Uganda where it was first discovered in 1947. Few human cases had been observed until 2007, when the vacation destination of Yap Island in the southwest Pacific Ocean had over 8,000 cases in three months. Because no one died and symptoms of fever, joint pain, eye inflammation, and rash resolved quickly, few were concerned (Cha & Sun, 2016). Research by Grard and colleagues (2007) found that the change of vector from *Aedes aegypti* to *A. albopictus* facilitated the spread and increased the virulence of Zika. Research by Harvey (2016) shows that climate change could increase the rate of infection by Zika due to the increase in the mosquito population.

As early as 2013, a connection between GBS and Zika was demonstrated (Oehler et al., 2014). GBS is an autoimmune disorder in which the immune system attacks motor neurons (CDC, 2016d). Zika, which arrived in Brazil in May of 2015, has resulted in a six-fold increase of GBS. In one hospital where 94 patients were treated, 50 of them died (Barchfield & Aleman, 2016).

Early in 2016, the Pan American Health Organization (PAHO) and World Health Organization (WHO) stated that an "increase of congenital anomalies, Guillain-Barré syndrome, and other neurological and autoimmune syndromes were found in areas where Zika virus is circulating" (Sun, 2016). One of those congenital anomalies is microcephaly, a rare condition in which brain development is retarded, and the baby is born with an abnormally small head. Symptoms include delayed or inhibited develop of motor skills. The virus may also cause blindness (Ventura et al., 2016).

Summary

In 1939, Guy Callender, a British engineer, made the connection between burning fossil fuels and global warming (Fleming, 2014). He could not have foreseen the ramifications of his prediction. It is not only the weather that has been affected by climate change. Subtle changes have already begun in mosquito populations: temperature increases, the mosquito population increases, their range increases, and ultimately, the number of people infected with mosquito-borne illnesses increases.

○ Discussion

Will the United States be as severely affected as the poorer countries? Probably not. The United States has kept at bay malaria and yellow fever by being vigilant. If people don't bring the disease back from infected areas, there is no reservoir to infect the local mosquitoes. CDC's Division of Vector-Borne Diseases (2016b) states uses cutting edge technology to diagnosis and combat disease, vaccination to prevent disease, and co-ordination between regions of the United States and educatation to slow the spread of mosquitoes.

There are two ways for us to reduce our chance of infection, vector control and personal protection. CDC's Mosquito-Borne Diseases website (2016a) asserts the first move in controlling mosquitoes is to remove standing water. Even a small amount of water can become a breeding spot. The CDC website (2016a) also states that when outdoors, people should protect themselves by using an EPA approved repellent and by wearing long-sleeved shirts and pants also treated with repellent.

CDC (2016b) states that education is an important part of preventing vector-borne diseases. Also, the effect of climate change on mosquito-borne disease is a worthy topic to be addressed in the biology classroom. Though the topic of climate change may be controversial in some states, the effect of mosquito-borne diseases is not. This topic can easily be addressed in the classroom. An AP Biology class could be challenged to design an experiment to test whether mosquitoes will hatch faster if their environment is warmer. If each group of students chooses a different temperature, a large amount of data will be available for analysis.

Many teachers do not have the luxury of time to develop their materials. The Yale Peabody Museum of Natural History Fellowship Program has developed an in-depth program entitled "Biodiversity and Vector-Borne Disease Curriculum," which can be found at http://peabody.yale.edu/teachers/curricula-vector-borne-disease. The program includes detailed lesson plans, pre- and post-assessments, teacher notes, and a list of materials. These lessons are hands-on and inquiry-based. In one lesson, groups of students are challenged to develop a new nature center. In this activity, a group must pick a locale and analyze breeding areas for vectors, then design a plan to reduce that vectors, as well as educate the public.

"Humans vs. Mosquitoes" (Ewing et al., 2013) is an entertaining game where students play the role of mosquito or human. After learning the mosquito life cycle, student must decide which habitats are breeding grounds and must be cleared. From this game, students learn how climate change and human behaviors can influence the spread of mosquito-borne diseases.

"Blood Suckers and Climate" is a jigsaw activity to help students understand greenhouse gasses and their effect on the atmosphere. As the atmosphere changes, the planet warms, and the amount precipitation changes in different areas. Students correlate the increase of several different mosquito-borne diseases (Dengue, malaria, West Nile) with changes in maps of temperature and precipitation. This jigsaw activity can be found that the following URL, http://peabody.yale.edu/teachers/peabody-fellows-institute/climate-and-emerging-infections-com panion-documents

The Climate and Emerging Infection curriculum is filled with lessons and activities appropriate for grades 6–12 (http://peabody.yale.edu/teachers/curricula-vector-borne-disease). Lessons include vocabulary, surface proteins, epidemiology, map reading, and malaria becoming resistant to vaccines. These curricula are rich in Next Generation Science Standards. For example, HS-LS2 (Interdependent Relations in Ecosystems) is covered in detail. Crosscutting concepts of cause and effect, as well as stability and change, are embedded in the concept being tested. Other core ideas such as evolution, inheritance, natural selection, and climate change are also presented.

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