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GSTR 410
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November 23, 2010

The Role of Climate Change on Current and Future Malaria Transmission

Abstract

In 2006, approximately 25 million people contracted malaria in Mozambique and Kenya. Despite the severity of this disease, scientists are unsure of the primary factor in malaria's ever increasing spread. Global climate change, drug and pesticide resistance, human migration and local climate changes are all possibilities. The future effects of global climate change on malaria transmission are also controversial. This study is an analysis and critique of the current literature on these topics. I conclude that global climate change as the prime disease factor is the best explanation of current malaria trends in Mozambique and Kenya. By 2100, climate change will cause increased malaria in Kenya and decreased malaria in Mozambique. Answers to questions about malaria's ecology addressed in this paper are critical for determining how to best approach malaria control programs and plan for the future of the disease.

Malaria in the here and now

Sub-Saharan Africa is comprised of nearly fifty sovereign states and over 600 million people (Packard 81). In this region, malaria accounts for almost one million deaths per year. Despite the severity of the disease inSub-Saharan Africa, epidemiologists question why malaria is increasing. Some say global climate change is to blame; others point to social, biological and local climate changes. Though the current role of global climate change on malaria is questionable, many scientists and the Intergovernmental Panel on Climate Change (IPCC) have predicted that future, more pronounced climate changes will surely increase malaria transmission. However, a growing group of scientists disagree; saying that climate change will make little difference or will actually decrease the incidence of malaria. Answers to these questions are crucial in determining how to best approach malaria control programs. Global climate change has and will have a noteworthy impact on malaria transmission because the rate of development and potential breeding sites are affected.

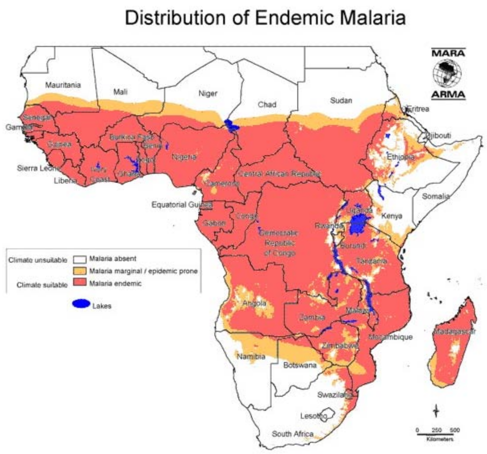

Figure 1. Distribution of Endemic Malaria in Sub-Saharan Africa from the University of Liverpool. Pink denotes that malaria is present all year round, orange indicates that the area is prone to seasonal epidemics, white represents no malaria.

In order to fulfill a more specific study and hopefully a more definite conclusion, Kenya and Mozambique will represent Sub-Saharan Africa in this paper. In 2006, malaria contributed to over 10,000 deaths in Mozambique and Kenya (WHO). Furthermore, it contributed to an estimated loss of 1.3% to economic growth every year from 1965-1990 (Packard 225). Kenya has seen a sharp increase in malaria in recent years. Accordingly, their malaria control fund went from $1 million in 2003 to $62 million in 2008 (WHO “Indicator Reported Cases;” WHO Kenya). In contrast, Mozambique’s malaria rates have risen gradually, mirroring the change in global temperatures (WHO “Indicator Reported Cases;” WHO Mozambique). We must call into question, however, the reliability of this data because reporting is known to be deficient in undeveloped countries. Thus increased case numbers may be related to better reporting and diagnosis of malaria.

Reported Malaria Cases

Year	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*
Kenya	6103447	434190	3777022	N/A	80718	122792	74194	3262931	3319399	5090639	7545541	9181224	7958704
Mozambique	N/A	N/A	12794	N/A	194024	2336640	3278525	3947335	4592799	4863406	5610884	5896411	6335757

Table 1. Reported Cases of Malaria from the World Health Organization.

Malaria, meaning "bad air," is one of the most common infectious diseases worldwide (Packard 36; Bloland 2). It is a vector-borne disease; meaning it is transmitted to humans via an anthropod. Specifically, malaria is caused by the parasite Plasmodium. The most problematic species of Plasmodium in Africa is P. falciparum (Packard 22.) which thrives at temperatures above 60°F, can invade all types of red blood cells and causes the most potent form of malaria (Packard 22; Boer 121). However, P. falciparum only survives in the human liver for a few months, compared to the 3-5 years commonly seen in other species (Packard 122). The vector/anthropod in question, and the focus of many malaria control programs, is the Anopheline mosquito. Only female mosquitoes feed on blood, a necessity in the production of eggs.. Their reproductive cycle takes approximately fourteen days, while the female mosquito's lifespan is 28 to 56 days (Packard 21). The malaria parasite must have time to infect the mosquito, mature and migrate to the mosquito's salivary glands before the insect's death in order to be transmitted to humans. This time sensitive scheme is very climate sensitive, leading some scientists to argue that climate change has impacted malaria.

The biggest contributing vectors for malaria transmission in Mozambique and Kenya are the Anopheline species A. gambiae and A. funestus (WHO Kenya; WHO Mozambique). A. gambiae and A. funestus are considered two of the most efficient transmitters of malaria, partly because they are anthropophilic, meaning they prefer human blood over the blood of other mammals (Packard 25). The mosquito unintentionally injects the malaria parasite into humans when feeding. The parasite then migrates to the host's liver where it matures and multiplies. The infected liver cells expand until they burst, releasing the parasites into the bloodstream, where they invade red blood cells, multiply and rupture as well (Packard 21; Boer 121). This cycle continues until the host dies, is treated or the parasite is restricted by the host's immune system response. This cycle produces fevers in the host every two to three days in relation to the red blood cells bursting. Sweating, chills, headache, reduced appetite, nausea, vomiting, and muscle pain are also commonly seen symptoms. More serious complications include severe anemia, pneumonia, seizures, and permanent brain damage (Boer 121; Malakooti, Biomndo and Shanks).

A type of semi-immunity to malaria can be acquired to specific species over a period of four to five years from frequent exposure, making the symptoms less severe (Packard 8). However, this leaves nonresistant groups, such as children, at high risk for malaria related morbidity and mortality. Due to this, one African child dies every second due to malaria (Packard 8). The high probability of losing a child leads African families to have multiple children, increasing the population and the possible host pool for mosquitoes. In the process, already compromised resources are further stressed by the growing population. Furthermore, malaria leads to absenteeism and decreased productivity at school and work (Republic of Mozambique 8). For example, malaria is thought to contribute to 8% of all school absentees in Kenya (Chuma 3). Malaria impedes productivity and thus economic growth and is thought to deter trade, foreign investments and tourism ("Malaria economic implications" 1).

It has been said that by the end of the 20th century "100 million extra cases (of malaria) occurred that would not have if not for global warming" (Boer 122). This statement is a controversial one because malaria transmission is dependent on several diverse factors. Some argue that the amount of climate change seen thus far has not been significant enough to affect malaria transmission. To date, the mean temperature of the Earth has increased by 1.73°F (0.76°C) since 1850 (Boer 182).Temperature influences the mosquitoes' feedings, population density and lifespan, as well as the malaria parasite's incubation period inside the arthropod (Small, Goethe & Hay, 15341; Paaimjanes 13845). In some areas, female mosquitoes have a lifespan of only twelve days, greatly reducing the chance for Plasmodium to develop and be transmitted to a host (Paaimjanes 13845).

Many scientists agree with the basic association between increased temperature and mosquito development. Increased temperatures speed up the metabolism and associated biochemical reactions in mosquitoes so that larval development occurs more rapidly and females require more frequent blood meals (Patz & Olson 5635; Boer 122). The precise effect of temperature on mosquitoes is more divisive; Patz and Olson concluded that the 0.5°C increase could boost mosquito abundance by 30-100% (5635). Furthermore, they found that at temperatures above 77°F, P. falciparum developed in only two weeks, compared to the normally required four (5635). Therefore, a temperature increase related to global climate change resulting from greenhouse gas emissions could increase the incidence of malaria in endemic areas. Additionally, this temperature spike can cause favorable conditions in historically malaria free areas. Highland areas are a perfect example of this. Temperatures drop with increased elevation, which inhibits mosquito habitation; typically mosquitoes cannot survive about 2500 ft. However, recent malaria epidemics have occurred in the highlands of Kenya; Kericho is one such area (Brown 129). Increased mean temperatures from 16.8°C to 17.8°C (62-63°F) in Kericho are believed to contribute toward climate suitability for the mosquito. Combined with increased daily fluctuations toward warmer temperatures, the increased mean temperature provides just enough time for Plasmodium to develop inside the mosquito and be transmitted to the unexposed population (Paaimjanes 13845). This idea spawned from the Kaufmann effect, which states that "biological processes are faster under fluctuating low temperatures" (Paaimjanes 13847). Essentially the warm fluctuations in the typically colder highlands act as a rescue catalyst for the developing parasite. The Kaufmann effect has been proven for some vector-borne pathogens, but has yet to be confirmed for malaria. If accurate, a significant increase in temperatures is not necessary for climate change to have a supportive effect on malaria transmission.

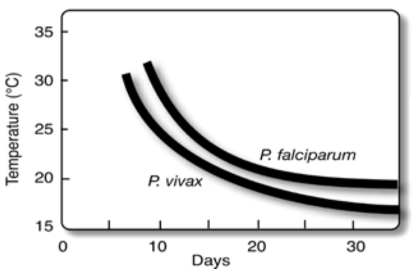

Figure 2. Relationship between temperature and development of 2 types of malaria parasites inside the mosquito. The incubation period is shorter at higher temperatures

Strong arguments against the view that current climate change has increased the incidence of malaria are few and far between. Randolph claims that the relationship between increased temperatures and increased malaria is an example of a "universal problem;" basing conclusions on superficial correlations (929). Other arguments cite the lack of considerable temperature increases and climate change in growing malaria ridden areas as proof that other non-climatic influences are chiefly to blame (Tanser 1797). As previously discussed, this argument may possibly be irrelevant if one considers the Kaufmann effect applicable to mosquitoes.

A positive association exists between heavy rains and malaria outbreaks (Lafferty 891). One example of this occurred in 1997-1998, when the Horn of Africa experienced long-lasting, drenching rains; a malaria epidemic broke out and quickly spread to the surrounding countries (Boer 146). However, rain can have different effects on different landscapes; where little to no water is present; rain can accumulate in ditches and pools and create a breeding ground for mosquitoes. Rain can also form free-flowing bodies of water, which creates a defective condition for mosquitoes to lay their eggs. In assessing climate changes' affect on rainfall, we can consider the study by Small, Goethe and Hay. They completed a retrospective study from 1911 -1995, looking at the climate suitability of six African regions for malaria. Rainfall was one of their climate variables. What they found was that rainfall increased during this period in Southern Mozambique leading to increased suitability to malaria in the region (15341). The other five areas studied showed no trends in any climatic variables over the 84 year period that would influence malaria transmission. The link between rain and malaria, together with the number of rainy seasons in Kenya and Mozambique, two and one respectively, may explain some of the malaria cases shown in Table 1 (BBC Mozambique; BBC Kenya).

Rainfall has been cited as the primary cause of malaria epidemics in four Kenyan highland areas. However, epidemics were shown to occur in years when there was very little rainfall. Conversely, in 1993 there was an excessive amount of rainfall and no epidemic. These facts suggest either other factors are at play or that rainfall only has a limited positive influence on malaria transmission ("Climate Change and Malaria"). For the most part, those downplaying the role of climate change in malaria incidence often do not directly attack the relationship between these two but rather report that non-climatic factors play a much bigger role.

The social, biological and local climate changes frequently cited as the cause of increased malaria cases in Sub-Saharan Africa include resistance to malaria drugs and pesticides, human migration and local climate change resulting from widespread deforestation and urbanization. Resistance is defined as the "ability of the parasite strain to survive and/or multiply despite the administration and absorption of a drug given in doses equal to or higher than those usually recommended" (Bloland 12). It occurs through single or multiple mutations in the plasmodium parasite granting decreased sensitivity to the anti-malarial drugs. The same occurs in mosquitoes with regards to pesticide resistance.

In 1955, the World Health Organization (WHO) began a malaria eradication program which involved wiping out the mosquito population with the pesticide DDT (Packard 163). The program was highly successful due to the low cost of DDT and the longevity of effectiveness for a single DDT spray (Packard 141). However, DDT’s harmful effects to the bird and human population became highly publicized in the 1960s. Moreover, 56-69 mosquito species developed resistance to the pesticide, leading to the WHO’s abandonment of the project in 1969 (Packard 163). This resistance likely occurred because DDT was affordable and thus widely used. However, many countries and local governments failed to properly instruct people on its use. As a result, many were watering down the DDT to make it last longer; exposing mosquitoes to sub-sufficient levels for extermination and allowing them to become resistant (Packard 166). Alternate pesticides were produced but cost 20x more than DDT and were thus outside of the African nation’s price range.

Beginning around the time of the Second World War chloroquinine was the drug of choice for malaria prevention and treatment (Packard 140). Yet, its usage had some of the same problems as DDT—people took sub-optimal levels and overused it. The vast majority of health clinics in Africa routinely diagnose malaria based on the clinical symptoms alone. For example, in 2005 49.6% of African children were given an anti-malarial agent for a potentially unrelated fever (Packard 225). Consequently, chloroquinine resistance is widespread; P. falciparum resistance to the drug ranges from 15-40%. Yet, this knowledge has not spilled over into clinical practices in Africa. In 2005, 95% of children were treated with chloroquinine (Packard 225).

Combination drugs are currently recommended as first and second line malaria treatments in most of Africa today. A pharmacological treatment plan is in place in both Mozambique and Kenya, however getting these drugs is a different story. Half of Mozambicans live over 20km away from a health facility (Republic of Mozambique 7). Even if they get there, it is not uncommon for the health facilities to run out of medicine. In 2001, 80% of all African health clinics were without anti-malaria agents for periods greater than a week (Republic of Mozambique 22).

Reliable data on malaria cases dating back before DDT and anti-malarial resistance was a problem is unavailable. However, it is clear that after DDT spraying was stopped, malaria transmission increased dramatically. In South Africa, malaria increased by 150% the year after spraying ceased ("A useful poison."). DDT spraying ceased in Mozambique and Kenya in the mid 1980s ("A useful poison."). Swaziland, a country bordering Mozambique, continued its DDT use and as a result its malaria rates are 20-40 times lower ("A useful poison."). Another fact stressing the importance of pesticide use is the recently released data that malaria cases fell by two million in Mozambique between 2007 and 2009 (allafrica.com). This is after an indoor and outdoor pesticide spraying and insecticide bed net program was implemented. The effects of anti-malaria drug resistance on the spread of malaria are harder to quantify though the assumption is reasonable. If an infected person is not cured from the malaria drugs because of drug resistance then the parasite survives in the bloodstream; this allows other mosquitoes who bite that person to become infected with the parasite and in turn spread it to other humans.

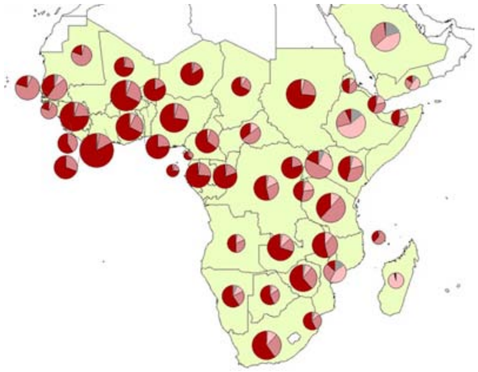

Figure 3. Incoming migrants by endemicity class; colored as: gray (unstable risk) light pink (0–5% risk), mid-pink (5–40% risk) & dark red (>40% risk). Pie chart size represents relative number of migrants. Tatem & Smith.

One of the biggest social factors in malaria is the incidence of internal African migration. Migration introduces parasites or different parasite strains to new areas. These parasites not only bring the disease, but also drug resistance (Hales & Woodward 1775; Lafferty 893). Plasmodium can stay in the host's body for months or years without producing symptoms. If such a person travels to a malaria free region, they can infect local mosquitoes when bitten (Tatem & Smith 1). Unfortunately, some of the largest numbers of migrants come from endemic areas (Tatem & Smith 2). This is probably because endemic areas are usually poorer and thus people are willing to travel for work. Mozambique is an example of one such area.

It is believed that malaria was brought to the Kenyan highlands via migrant workers from the endemic lowlands that had come for plantation work (Packard 90). Though data on internal migration in Africa is limited, suspected numbers reach 20-25 million (Black 17). It is thought to be extensive because of rapid population growth and increased mobility (Prothero 2). As the population grows, stress is placed on resources and people are forced to migrate for opportunity. Most migration is thought to be from rural to urban areas (Black 26).

Urbanization, in itself, is a factor for increased malaria transmission for several reasons. For one, it creates a denser population and thus more opportunities for blood meals for potentially infected mosquitoes. Second, urban areas suffer from the 'urban heat island effect,' which is when cities are warmer than surrounding areas due to energy usage, retained heat from building materials, etc (Lafferty 894). This local climate change, like global, can potentiate mosquito development and feeding frequencies. 37% of Mozambique's population was urban in 2008, compared to 22% for Kenya; both have a 4% annual urbanization growth rate (U.S. Central Intelligence Agency).

Another cause of local climate change and a much talked about factor in increased malaria, is deforestation. Trees are the primary energy source for all of Sub-Saharan Africa. Cutting down trees releases carbon dioxide into the atmosphere, causing an increase in global climate change. However, deforestation changes the local climate at a much faster rate (Patz & Olson 5635). It affects every element of the ecosystem through increases in ground temperatures, higher risks of pooling water as root systems are no longer present to absorb them, and altering rainfall patterns, air movement, and humidity, etc (Uneke 6). These changes are favorable for the breeding habits of some species of mosquito. Coincidentally, A. gambiae, an extremely efficient malaria vector, is one species that benefits. A. gambiaes' eggs have a 50 times increased survivorship in sunlit over forested areas and the adult mosquitoes' vector capacity is increased by 29% (Patz & Olson 5635; Uneke 7). Additionally, deforestation destroys animal habitats, giving mosquitoes less options for blood meals (Uneke 7).

Square Kilometers of Forest															
Year	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*
Kenya	37080	36954	36828	36702	36576	36450	36324	36198	36072	35946	35820	35700	35580	35460	35340
Mozambique	200120	199620	199120	198620	198120	197620	197120	196620	196120	195620	195120	194620	194120	193620	193120

Table 2. Square kilometers of forest from World Development Indicators. Notice the decreasing figures (forest land) over time.

burn agriculture;' people clear one stretch of forest, turning it into cropland, they leave to clear another forest but do not replant in the process (Uneke 5). Some of the most malaria ridden regions also have the largest forests and thus potential to worsen the disease through deforestation (Uneke 9). Treeless areas create warmer middays, shortening the mosquitoes' egg production and laying cycle. In Kenya, where 120 square kilometers were cut down in 2007, deforested areas were shown to increase the mosquitoes' net reproductive rate by 38.5-40.6% (world development indicators; Uneke 7). The deforestation rates for both Kenya and Mozambique are rather steady with a slow decline. Mozambique tore down 500 square km of forest in 2007, which is may be tolerable considering that a quarter of the country is covered in forests (World Bank).

Malaria is a multi-factorial disease; the increased incidences in Kenya and Mozambique are, without a doubt, affected by global and local climate change, drug and pesticide resistance and human migration, among other things. However, in considering the specifics of each factor we can eliminate some as the primary factor. Deforestation surely has a positive effect on mosquito breeding, but the rates have been declining in both countries while the malaria rates increase. Migration probably introduced malaria to the Kenyan highlands, but I doubt it alone is the cause of its rapid proliferation. Migration is probably not a strong factor at all for Mozambique, as much of the country is endemic with malaria and has been for several decades. Urbanization and its steady growth rates in Mozambique and Kenya may be a contender, particularly in Mozambique where there is a gradual rise in malaria year after year. However, because the urbanization rate is the same for the two countries, it does not explain Kenya's malaria trends. The elimination of DDT had a large affect on increased malaria in the 1980s and theoretically, mosquitoes would be permitted to gain ground yearly afterwards. This makes sense for Mozambique's pattern of malaria, but not for Kenya, who has seen drastic increases in malaria rates many years after the cessation of DDT use. Anti-malarial drug resistance is another potential contender; we have had effective disease treatments since the early 1900s. Now it seems we are running out of options and the accessibility of the drugs that do work is compromised by distance and price. Increased migration further complicates the problem by spreading drug immune parasites. Nonetheless, this does not explain Kenya's sharp increase in malaria. The most controversial factor in malaria, global climate change, is probably the hardest to argue considering our current knowledge on the temperature and malaria relationship. We have only seen a 0.76°C increase related to global climate change, but if the Kaufmann effect is indeed true for malaria then this, plus increased daily variability, also climate change related, is plenty to cause increased malaria. This could explain the gradual increase in Mozambique and the sharp increase in Kenya, as the highlands become newly favorable to transmission from the temperature increase. Though the Kaufmann effect has yet to be proven, it is likely applicable to malaria, like it is to other vector-borne diseases. Furthermore, global climate change is the only factor discussed that explains the malaria trends for both Mozambique and Kenya. In conclusion, global climate change as the prime disease factor is the best explanation of current malaria trends in Mozambique and Kenya.

Malaria in the future

A wholly different debate on the association between climate and malaria pertains to the future effects of global climate change on the disease. While many dispute the effects of the relatively small climate changes we have seen thus far, a large number of scientist agree that more pronounced climate changes, which we very likely can expect in the future, will have a positive effect on the spread of malaria. However, just recently, scientists have unexpectedly emerged, asking the scientific community to reconsider these claims. They declare that malaria changes will be region specific and some aspects of climate change may actually cause malaria to decline. In order to assess the likely prospects of malaria we will limit our focus on the future to the year 2100.

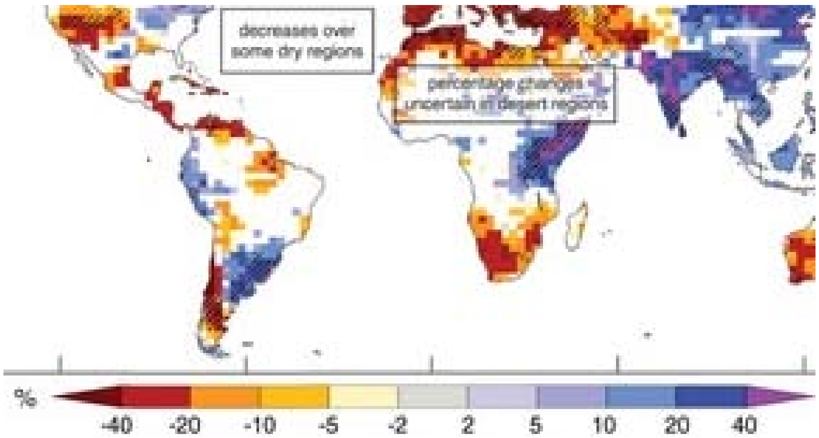

Figure 4. Projected Precipitation Changes from IPCC. Regional Climate Projections

The IPCC has compiled all of our scientific knowledge concerning climate change to make predictions for our future climate. They purport that all of Africa can expect a 3-4°C temperature increase by the year 2100 (866). More extreme rain events are expected to occur amongst increased probability of drought (Lynas 173; Conway 10). Kenya's precipitation rates are expected to have a 0 to +5 fractional change, while Mozambique's precipitation is expected to have a -10% change (IPCC 869). The country's spring rain season will also be delayed; overall the country is expected to become much dryer, while Kenya will become wetter with greater humidity.

As stated earlier in this paper, increased temperatures accelerate the development of the malaria parasite and mosquito, increasing the chance of both being mature enough to transmit malaria to humans (Conway 13). Tanser and his colleagues developed three models to study the relationship between temperature and malaria and all three showed an increased 16-28% length in transmission season. A 5-7% distribution increase was also predicted, mainly related to increased suitability of higher altitudes (Tanser 1792). As we have already seen in areas like Kericho, Kenya, highland areas will become suitable for mosquitoes which inherently will increase the incidence of malaria. However, with increased daily minimum temperatures, mosquitoes will no longer be at the mercy of fluctuating high temperatures in relation to the Kaufmann effect; the average temperature alone will be suitable for them (Conway 10). Temperature increases above 2.5°C will also cause a sharp decline in crop outputs leading to widespread starvation and increased migration. Increased migration and likely urbanization will only perpetuate the spread of malaria (Lynas 180). Increased rainfall and extreme rain events are currently associated with malaria epidemics, so these climate change events will likely spread malaria. On the other hand, drought is also foreseen to occur; Tanser explains that though monthly rainfall thresholds may not be reached, enough may fall to create pools of standing water, which are perfect breeding spots for mosquitoes (1797).

Hales and Woodward agree with the widely accepted relationship between temperature and malaria. However, they claim it is an oversimplification of the disease’s ecology to say that future climate change will undoubtedly equal increased malaria (1775). They assert that some parts of Africa, such as Mozambique, will be too dry and hot for mosquitoes, which prefer warm and wet conditions (1797). Others agree with this statement, pushing the fact that mosquitoes come out in the evening when the temperatures have cooled. Their preferred temperature range is 60-85°F; once you get past 95°F mosquito survival starts to decline (Paaijimanes 13845). With increased mean and maximum temperatures related to global warming, perhaps evening temperature will also be too hot for the vectors. Further, the other side of the Kaufmann effect says that biological processes are slower under fluctuating high temperatures, so increased temperatures may slow parasite and mosquito development (Paaimijanes 13847). Furthermore, Hales and Woodward dispute the reliability of the three models used by Tanser because he did not include the effectiveness of healthcare and vector control programs (1775).

Others argue that global climate change will have little effect on malaria transmission because it will cause a shift, not an expansion, in disease suitability (Lafftery 897). As the temperature increases worldwide some lowland areas, where malaria is now endemic, will become too hot for mosquitoes to tolerate, causing them to migrate to higher altitude areas. Lafferty estimates that malaria will gain 23million new hosts by 2050, but will lose 25million in the process; little ground will be gained (897). Lafferty also reminds us that increased suitability in areas does not necessarily equate with increased disease, because competition and predation in the new areas has an impact (897). Hales and Woodward also conclude that malaria will remain relatively stable with climate change, but for different reasons. They believe the disease incidence will not increase significantly because it will only concentrate in areas it already exists due to an extension of the seasonality (1775).

The effects of global climate change on malaria by the year 2100 will depend on the region in question and the changes it has undergone. Areas becoming drier will likely see a decline in transmission, while areas receiving more rain will see an increase. Much of Mozambique will become more arid and suffer from extreme and prolonged droughts; mosquitoes will have less places to breed and will be stifled by the oppressive heat, leading to a decline in their numbers and malaria transmission. Kenya on the other hand will see a significant increase in malaria related to increased rainfall and increased suitability of highland areas, which happen to be the most densely populated. The impact of disease will be greater here because the population is mostly unexposed and without immunity. Concerning Hales and Woodward's argument that Tanser should have include vector control and healthcare into his model; it is extremely difficult to guess what future measures will be taken in these areas considering the drug and pesticide resistance we see today. Furthermore, if we remember the social implications tied to a 3-4°C temperature increase, we will remember that a breakdown in social and political systems is very likely, which would greatly hamper healthcare and vector control programs.

Malaria is a problem and it will continue to be in the future. The best method of alleviating and possibly eradicating the disease is through ending poverty. It has shown to be effective in other areas of the world, like Northern Europe in the 17th century (Packard 36). Bettering the economic condition of Sub-Saharan Africa would allow them to invest more money into their eradication and drug programs and cut down on deforestation rates. It would allow them to improve their tracking of malaria and inland migration so that epidemiologists and scientists could answer the question of why malaria keeps rising. Halting deforestation would not only assist in decreasing malaria transmission, but in the emissions of greenhouse gases as well. Global climate change will have a catastrophic effect on Sub-Saharan Africa; it will increase malaria, food and water scarcity and political chaos. As a large and ever growing factor in malaria's ecology, climate change mitigation should be included in malaria control programs. Sub-Saharan Africans should take responsibility for their future by limiting deforestation and moreover, push developed nations to be accountable for their actions or lack thereof on climate change.

Works Cited

"A useful poison." Economist 357 (14 Dec 2000). <http://www.malaria.org/DDTEconomist14_XII_00.html>

Black, Richard. “Migration and Pro-Poor Policy in Africa.” Sussex Centre for Migration Research. Nov 2004. < www.migrationdrc.org/publications/working_papers/WP-C6.pdf>

Bloland Peter B. Malaria Control during Mass Population Movement and Natural Disasters. Washington D.C.: National Academies, 2003.

Boer, Hans A. Global Warming and the Political Ecology of Health. California: Left Coast, 2008.

British Broadcasting Company. “Country Guide: Kenya.” BBC Weather. 25 Nov. 2010 < http://www.bbc.co.uk/weather/world/country_guides/results.shtml?tt=TT000300>

British Broadcasting Company. “Country Guide: Mozambique.” BBC Weather. 25 Nov. 2010 < http://www.bbc.co.uk/weather/world/country_guides/results.shtml?tt=TT000430>

Brown, Paul. Global Warming: Can Civilization Survive? London: Blanford, 1996.

Chuma, Jane, Vincent Okungu, and Catherine Molyneux. "The economic costs of malaria in four Kenyan districts: do household costs differ by disease endemicity?." *Malaria Journal* 9.(2010): 149. *MEDLINE*. EBSCO. Web. 26 Sept. 2010. <http://web.ebscohost.com.www.berea.edu:9005/ehost/pdfviewer/pdfviewer?vid=9&hid =9&sid=9faf154e-f8bf-4608-bcca-4f5abb9f5e60%40sessionmgr13>

“Climate Change and Malaria.” Brown University. 17 May. 2000. < http://www.brown.edu/ Research/EnvStudies_Theses/full9900/creid/climate_change_and_malaria.htm>

Conway, Gordon. “The science of climate change in Africa: impacts and adaptations.” Grantham Institute for Climate Change Discussion paper No 1. Oct 2009.

Hales, S, and A Woodward. "Climate change will increase demands on malaria control in Africa." *Lancet* 362.9398 (2003): 1775. *CINAHL*. EBSCO. Web. 26 Sept. 2010.

<http://web.ebscohost.com.www.berea.edu:9005/ehost/pdfviewer/pdfviewer?vid=7&hid=9&sid=8e5218b1-79ca-4713-81a5-96a99349eb0c%40sessionmgr12>

IPCC. Regional Climate Projections. <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter11.pdf>

Lafferty, Kevin D. “ The ecology of climate change and infectious diseases.” Ecology 90 (Apr 2009): 888-900

Lynas, Mark. Six Degrees: Our Future on a Hotter Planet. Washington D.C.: National Geographic, 2008.

Malakooti, M.A., K. Biomndo and G.C. Shanks. “Reemergence of Epidemic Malaria is the Highlands of Western Kenya.” Emerging Infectious Diseases 4 (Oct-Dec 1998). <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2640260/pdf/9866748.pdf>

“Malaria economic implications.” Weekly Epidemiological Record 39 (29 Sept 2000).

“Mozambique: Malaria Cases Cut By a Third.” AllAfrica.com. 2 Nov 2010. < http://allafrica.com/stories/201011030149.html>

Paaijimans, Krijn P., Andrew F. Read and Matthew B. Thomas. “Understanding the link between malaria risk and climate.” Proceedings of the National Academy of Sciences of the United States of America 106 (Aug 2009): 13844-13849.

Packard, Randall M. The Making of a Tropical Disease: A Short History of Malaria. Baltimore: John Hopkins University Press, 2007.

Patz, Jonathan A. and Sarah H. Olson. “Malaria risk and temperature:Influences from global climate change and local land use practice.” Proceedings of the National Academy of Sciences of the United States of America 103 (Apr 2006): 5635-5636.

Prothero, R. Mansell. “Migration and Malaria.” Pittsburgh: University of Pittsburgh. 18 Oct 2010. <http://www.aifo.it/english/resources/online/books/other/malaria/15Migration%20%26%20Malaria.pdf

Randolph, Sarah E. “Perspectives on climate change impacts on infectious diseases.” Ecology. 90.4 (2009): 927-931.

Republic of Mozambique. Ministry of Health. Strategic Plan for Malaria Control in Mozambique. July 2006.

Small, Jennifer, Scott J. Goetz and Simon I. Hays. “Climatic suitability for malaria transmission in Africa, 1911–1995.” Proceedings of the National Academy of Sciences of the United States of America 100 (Dec 2003): 15341-15345.

Tanser, FC, B Sharp, and D le Sueur. "Potential effect of climate change on malaria transmission in Africa." *Lancet* 362.9398 (2003): 1792-1798. *CINAHL*. EBSCO. Web. 26 Sept. 2010. <http://web.ebscohost.com.www.berea.edu:9005/ehost/pdfviewer/pdfviewer?vid=6&hid=9&sid=8e5218b1-79ca-4713-81a5-96a99349eb0c%40sessionmgr12>

Tatem, Andre J. and David L. Smith. “International population movements and regional Plasmodium falciparum malaria elimination strategies.” Proceedings of the National Academy of Sciences of theUnited States of America (21 Jun 2010). 18 Oct 2010. < http://www.pnas.org/content/early/2010/06/07/1002971107.full.pdf+html?sid=685a566e-8e25-498f-bc15-06356b6f3921

Uneke, C. J. "Deforestation and Malaria in sub-Saharan Africa: an overview." Internet Journal of Tropical Medicine 6.1 (2009): 2.<http://web.ebscohost.com.www.berea.edu:9005/ehost/detail?vid=5&hid=108&sid=0aca639d-acf0-4058-890f-5d93215c8fd7%40sessionmgr112&bdata=JnNpdGU9ZWhvc3Qtb Gl2ZQ%3d%3d>

United States. Central Intelligence Agency. The World Fact Book: Urbanization. 3 Nov. 2010 <https://www.cia.gov/library/publications/the-world-factbook/fields/2212.html>

University of Liverpool. “Section 3: Malaria and Modeling.” Nov 9, 2010 from <http://www.liv.ac.uk/geography/research_projects/epidemics/MAL_geography.htm>

World Bank. “Forest Area (sq.km).” gapminder.org. 17 Oct. 2010. <http://www.gapminder.org/data/>

World Health Organization. “Indicator Reported Malaria Cases.” Gapminder.org. 19 Sept. 2010. < http://spreadsheets.google.com/pub?key=pp59adS3CHWczfPHQMiqxCg&gid=0>

World Health Organization. “World Malaria Report 2009: Kenya.” WHO.int. 4 Oct 2010. < http://www.who.int/malaria/publications/country-profiles/profile_ken_en.pdf>

World Health Organization. “World Malaria Report 2009: Mozambique.” WHO.int. 4 Oct 2010. < http://www.who.int/malaria/publications/country-profiles/profile_ moz_en.pdf>