CLIMATE CHANGE AND PUBLIC HEALTH:

MALARIA

An Overview of the Impact of Climate Change on Public Health with Regard to Malaria’s Cause, Treatment and Resurgence
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WHAT IS CLIMATE CHANGE AND WHAT ARE SOME PREDICTED IMPACTS?

Over the past century, Earth’s climate has warmed by 1.4 °F and is projected to continue to rise 2 - 11.5 °F over the next century (EPA 2014), depending on how quickly humanity can transition to a society limiting fossil fuel combustion. Rising global temperatures can be directly correlated with rising levels of atmospheric carbon dioxide. This increase in atmospheric carbon dioxide is due to human consumption of fossil fuels since the Industrial Revolution, accompanied with an ever-growing global population.

Carbon dioxide is a greenhouse gas, which acts as a blanket over the Earth. The greenhouse gas layer (made up of carbon dioxide and other greenhouse gases including water vapor, methane, chlorofluorocarbons (CFC’s), and nitrous oxide) blocks the long-wave radiation that is radiating from Earth back towards space, trapping it in the atmosphere, which warms the Earth. This is known as the Greenhouse Effect and is the main cause of global warming and climate change.

Temperatures are not only rising, but they are also becoming more variable, with recent decades showing unprecedented hot and cold extremes. Extreme heat events kill more people in the United States every year than all other weather events combined (NIEHS 2009) and these numbers are only likely to increase in the face of climate change.

Precipitation patterns will also likely be affected by climate change, and these changes can vary greatly from region to region. Changes in rainfall and prolonged droughts can be devastating to people that live in desert climates and are already water-stressed, as well as threaten the livelihoods of millions of farmers and fisherman worldwide. Drought-induced water shortages now leave one in nine people globally without a clean water source (Water.org 2014) and additional pollution has led to increased rates of water and food-borne diseases and malnutrition.

Other climate change impacts include ocean acidification, the melting of alpine glaciers and polar ice caps, sea level rise and associated flooding, species extinction, increased frequency and severity of extreme weather events, increased frequency and intensity of forest fires and the rapid spread of vector-borne diseases, such as malaria. It is important to keep in mind that not all places will be affected equally and that some regions, especially coastal or low-lying island nations and polar regions, will likely see much more drastic and immediate climate changes. There is also a large disparity of adaptive capacity between wealthy and poor countries with regard to their ability and available resources to cope with climate change impacts, which adds an ethical component to viable options for climate change solutions.
Is it human caused?

As far as scientists are concerned, there is no debate about whether climate change is real or whether it is human-caused. The answer is a simple yes. Over 99% of scientists say that the Earth is warming and that the warming is anthropogenic. Scientists have run Global Climate Models (GCM’s) that have shown that the amount of warming in the previous century could not have been due to natural factors alone, and the trend lines don’t come close to matching up until the human radiative forcing component is added in. The radiative forcing contributed by natural factors, like volcanoes and solar output variability, is miniscule compared to the added greenhouse effect of the 36 billion metric tons of carbon dioxide emitted by humans in 2013 alone. The rising levels of carbon dioxide that have been measured at Mauna Loa since 1958 are undisputedly due to human combustion of fossil fuels.

If scientists agree then why is climate change so controversial?

The words “global warming” and “climate change” have become very controversial phrases in modern-day society. A mere mention of these words in public can instigate responses that vary from one extreme to the other. But if it’s not that there is disagreement among the scientific community or that there’s not adequate evidence backing up the validity of climate change, then why is there still such a disagreement over it in America? Perhaps because the topic has been extremely politicized by competing interest groups and the spread of invalid science by the media, or valid science that has been taken out-of-context. Many companies have invested interest in petroleum and fear the enormity of infrastructure change that would be required to transition to renewable fuel sources.

Another reason why many Americans are skeptical to acknowledge the imminent threat of climate change is due to the inherent uncertainty in climate science. It is difficult to give exact predictions for how the climate will change in specific regions, as it will vary greatly from place to place. The general public often takes this as a sign of weak science, and as an excuse to dismiss the urgency, as they want to know exactly when and exactly how they will be affected. People are reluctant to change their way of life if they don’t see any short-term benefits. Renewable energy sources, like solar and wind power, often require an up-front investment (which will of course eventually pay itself back and then some), but people tend to think in short-term rather than long-term time frames.

Still another barrier to climate change supporters is the sheer magnitude of the problem. Climate change is truly a global issue and will require collective, cooperative and large-scale action in order to lower carbon emissions significantly enough to ensure a suitable planet for the generations to come. It will take major policy changes worldwide to effectively mitigate the carbon already in the atmosphere, while adapting to the already certain changes associated with past carbon consumption. Though this seems daunting and may discourage many from feeling like they can single-handedly make a difference, it is not an impossible task. Many technologies have already been developed that could change the way we view energy consumption and will soon be commercially available and affordable. Despite all the evidence, many Americans still debate whether climate change is real and continue to argue over its cause.
How will public health be impacted by climate change?

Climate change is expected to impact public health in a range of pathways, some more severe than others and some more predictable than others. Poorer countries are expected to be hit harder by the health impacts associated with climate change, as they lack important resources and funds to cope with these changes. Still, wealthy countries will not be immune from these impacts, as was demonstrated by the 2003 European heat wave that claimed over 35,000 lives. Similar to environmental impacts, health impacts will vary from region to region and exact predictions for specific places are still uncertain. Predicted health impacts range from increased rates of heat, flood or drought-related deaths, to increased diagnoses of allergies and asthma, to increased transmission of vector-borne diseases, such as malaria.

Diagnoses for chronic respiratory diseases have spiked worldwide in the last decade. The Center for Disease Control reports that in 2009, one in twelve people in the United States has asthma, compared to one in fourteen just eight years earlier, and this number continues to rise today (CDC 2009). This rise can be attributable to climatic changes that have led to exposure to new pollens, toxins, molds and dust. Densely urbanized areas that run on fossil fuels have led to extremely poor air quality in many cities around the world, which has led to deteriorating pulmonary health.

Cancer is the second leading cause of death in the United States, killing more than half a million people each year (NIEHS 2009). Increased intensity and duration of ultraviolet radiation has led to increased incidence of skin cancer. Additionally, along with the benefits of new alternative energy development comes the unexpected adverse
effects inherent with unprecedented discoveries. Nuclear energy, as well as battery and solar voltaic cell development are a step towards lowering carbon emissions, but create dangerous waste products and the potential for serious accidents that the ramifications of are not yet fully understood. Potential radiation damage from a major nuclear power plant accident could be catastrophic, as we have been warned from past disasters like Chernobyl.

Increased human waste and pollution, as well as changing global precipitation patterns, contribute to high rates of infection from food and water-borne pathogens. Today’s higher than ever before concentrations of chemical contaminants, biotoxins, insecticides and pesticides in crucial aquifers contribute to these problems and lead to decreased food and water availability. This is ultimately responsible for the deaths of thousands each year.

**VECTOR-BORNE DISEASES**

Arguably the biggest threat to public health presented by climate change is the potential for an epidemic outbreak of vector-borne infectious diseases. This potential stems from the range expansion of important vectors that these pathogens require to flourish, due to increased temperatures and humidity associated with climate change. A vector-borne disease is a term used to describe an illness that is caused by a microbe but transmitted via another host. Common vectors include mosquitoes, fleas, ticks, lice, mites and other blood-sucking arthropods. Vectors typically become infected while feeding on an infected vertebrate, and then pass the infection on to other susceptible people or animals. The vector host itself is often not affected by the microbe, but merely transmits the microbe into another host.

Vectors like the *Anopheles* mosquito, which carry and spread the protozoa that cause malaria, can now survive at higher elevations and higher latitudes than ever before. This means that malaria is becoming a threat in places that have never had problems with it historically. There has recently been a resurgence of malaria in East Africa that threatens the lives of millions of people. Malaria is a treatable and preventable disease, although if left untreated can be very serious, even fatal. The infection and transmission of malaria, as well as its associated solutions and challenges will be the focus of the remainder of this article.
What is malaria and how do you get it?

A genus of parasites called *Plasmodium* cause malaria, using the *Anopheles* mosquito as a vector. The mosquito is not affected by the parasite, but when an infected mosquito bites a human, the human will contract malaria. Malaria induces a high fever, shaking chills, nausea, and other flu-like symptoms in an infected patient. The parasite that causes malaria can lie dormant in the human body and cause relapses of symptoms years after the initial infection.

**Is it treatable?**

Although it is considered a treatable disease, if left untreated malaria can be fatal. There are several medications available for treatment and they vary depending on the age of the patient, the severity of the malaria, which species of parasite is the pathogen at hand, and whether or not the patient is pregnant. The most common anti-malarial drugs include chloroquine, quinine sulfate, Mefloquine, and other quinine derivatives (Mayo Clinic 2014).

**Is it preventable?**

There is currently no vaccine available for malaria prevention, although there is ongoing research working to develop one. The World Health Organization and the Center for Disease Control both recommend vector control as the best prevention. People planning to travel to malaria-endemic regions are advised to bring insecticide and wear mosquito nets when necessary. There are also chemoprophylaxis anti-malarial medications available, which suppress the blood stage of malarial infections, thereby preventing the disease (WHO 2013).

**DID YOU KNOW?**

Quinine is name after “quina,” the Quechua word for “holy bark.” The Quechua are Indigenous Peruvians who discovered the medicinal properties of quinine long ago. Quinine comes from the bark of the cinchona tree, and is marked by its bitter taste (mixed with sweetened water to make tonic water!) The Quechua used quinine as a muscle relaxant to prevent muscle spasms from constant shivering in the harsh Andes winters, and its anti-malarial properties were discovered in Europe in the 17th century.
A CLOSER LOOK...

The Culprit:

*Plasmodium*

The *Plasmodium* species are a type of parasitic protozoa (unicellular eukaryotes) that have a complex life cycle involving two hosts—the mosquito and the human. There are four species of *Plasmodium* that cause malaria in humans: *P. falciparum*, *P. vivax*, *P. malariae*, and *P. ovale*. *P. falciparum* is the most common and the most deadly. Previously thought to only affect monkeys, a fifth species, *P. knowlesi*, has now been confirmed to cause malaria in humans as well (WHO 2013).

*Anopheles*

There are about twenty species of mosquitoes in the *Anopheles* genus that live in tropical regions around the world. These mosquitoes like warm, humid climates and feed on human and animal blood around dusk and after nightfall. The *Plasmodium* parasites are transmitted only via female mosquitoes and the mosquito itself is not affected by the presence of the parasite; it only acts as a vector for the *Plasmodium* to find its next host and begin replicating.

After being ingested by the mosquito, the parasite must undergo a 10-21 day incubation period inside the mosquito before becoming virulent and having the potential to infect humans. This opens a window for prevention, as mosquitoes have a relatively short life span, and if they are killed before this incubation period is up, malaria transmission can be controlled. However, some species of *Anopheles* are longer-lived, especially the African species, which is why malaria is a bigger threat in regions home to that particular species (WHO 2013).

Sickle Cell Anemia

Interestingly, research has shown that people who are carriers for sickle cell anemia may have some form of resistance against malaria. Sickle cell anemia is a disease caused by a mutated gene that codes for abnormal hemoglobin, affecting red blood cell’s capacity to exchange oxygen and lowering the life expectancy of the individual significantly. This disease is passed down genetically, and the inheritance of the mutated gene from both sides is required to get the disease. However, being a carrier, (i.e. inheriting the gene from only one side) means you may be less susceptible to contracting malaria (CDC 2014). Many Africans that live in malaria endemic regions are carriers for sickle cell anemia. However, this does not guarantee protection and the best prevention is still control of the vector.

The above diagram illustrates the possible genetic outcomes for offspring of two parents who are carriers for the sickle cell gene.
When a female *Anopheles* mosquito picks up a certain form of gametocyte “blood stage” *Plasmodium* during a blood meal, they start another different cycle of growth and replication. After 10-18 days the *Plasmodium* are found as sporozoites in the mosquito’s salivary glands, and the next time they bite a human, the sporozoites are injected and the human will contract malaria.

The sporozoites infect human liver cells and mature into schizonts, which rupture and release merozoites in just six days. These are daughter parasites that go on to invade red blood cells. As the parasite replicates inside red blood cells, they create toxic waste products, such as hemozoin, that accumulate in the red blood cell. The cell will eventually lyse and these toxic factors are released into the bloodstream. This stimulates macrophages and other defense cells to produce cytokines, which acts to produce a fever and an immune response, influencing the severe pathophysiology associated with malaria (CDC 2014).
What affects transmission?

Transmission of malaria can be affected by a number of different things. The lifespan of the mosquito, the mosquito’s resistance to insecticides, the susceptibility of that particular Plasmodium species to anti-malarial drugs, and the susceptibility of the human to infection all are part of determining transmission rates. Young children and infants, travelers from areas with no malaria and pregnant women are at an increased risk for contracting malaria. Poverty, lack of education and access to healthcare also contribute to the high rates of malaria in Africa and Southeast Asia (Mayo Clinic 2014).

Also playing a crucial role in the transmission rates of malaria is climate. Increased global temperatures and altered seasonal precipitation has meant an increase in malaria victims worldwide. This is partly due to the increased range of the Anopheles mosquitoes, as with warmer temperatures, they can survive at higher elevations and higher latitudes than ever before. Both increased average daily means and increased daily temperature fluctuations, in addition to precipitation changes, have helped mosquitoes to thrive in recent years, meaning worse than ever conditions for malaria transmission.

Additionally, the degree of infection is dependent upon which species of Plasmodium the patient is infected with. P. vivax and P. ovale can remain in the body for years lying dormant. If left untreated, these species can cause relapses months or even years after the initial infection (CDC 2014).

Who is at risk?

The World Health Organization estimated in December that there were 207 million cases of malaria worldwide in 2012, resulting in 627,000 deaths. Most of these deaths occurred in Africa, where a child dies every minute from malaria. Ninety percent of deaths due to malaria are in sub-Saharan Africa and seventy percent of deaths are in children under the age of five. Still, these rates are down about 54% since 2000 due to education and prevention efforts (WHO 2013).

In the United States, an average of 1,500 cases of malaria are reported each year, though there has not been endemic malaria in the United States since the 1950’s. These outbreaks are from a local mosquito biting an infected person (someone who traveled to an endemic region and unknowingly brought the parasite home with them), and then transmitting the infection to other local residents. This means that there is a constant risk of malaria being reintroduced to the United States (CDC 2014).

There are approximately 3.3 billion people worldwide that live in areas where they are at risk of contracting malaria. Women who are pregnant and those with another pre-existing disease, such as HIV compromises the immune system and puts those individuals at a higher risk (WHO 2013).

Insecticide-treated mosquito nets greatly lower the transmission rate of malaria and provide an easy, non-invasive prevention method.
Historically malaria has been a threat in poor tropical and subtropical countries around the globe. While Africa is home to the highest malaria risk worldwide, parts of Southeast Asia and South America are also at risk. Direct costs of malaria in Africa are estimated to be at least US $12 billion annually and this doesn’t take into consideration the cost lost in economic growth and lost productivity of society (WHO 2014).

There are a number of reasons why Africa tends to be the most affected by malaria. First, Africa is home to a group of species of mosquitoes known as the *Anopheles gambiae* complex, which is a group of seven morphologically indistinguishable species of mosquitoes that are very efficient vectors. While on one hand having the most efficient vector, Africa is also home to the most severe and deadly form of the malaria-causing parasite, *Plasmodium falciparum*. This combination of mosquito and parasite had led to very high malaria rates in Africa (CDC 2014). On top of these reasons, Africa tends to have scarce resources and socio-economic and political instability that have hindered malaria control and prevention efforts.

This graphic was taken from Priya Shetty’s April 2012 article in Nature, “The Numbers Game.”
What is the predicted impact of malaria in the future?

In the face of climate change, malaria ranges are quickly expanding, though it is a complex relationship that is still being researched. Parts of Africa that have never been affected by malaria are now seeing their populations decimated by this disease. This increased mortality is partly due to lack of preventative resources or adequate medications for treatment, but a large reason for this range expansion is due the expanded range of the *Anopheles* mosquito. With warmer temperatures across much of Africa and other subtropical regions over the past few decades, both mosquitoes and the *Plasmodium* parasite are thriving year-round. The historical range is roughly 65° N and 40° S, however this is now reaching further north and south. In the past, it was rare to find cases of malaria above 3000-meter elevation, although with steadily increasing global temperatures, this demarcation elevation is being pushed higher every year. Another issue is that these populations have no previous exposure or immunity to malaria, so they will likely be hit harder with higher death tolls than areas that have been previously exposed.

The ideal temperature for transmission of malaria is 20-30 °C (68-86 °F). *Anopheles* mosquitoes do not breed below 16 °C (60°F) (American College of Physicians 2009). Many parts of Africa now reach this ideal temperature range earlier in the season and remain warmer later in the season and through nights than previously. This means rates of transmission are higher than ever before. Transmission is also increased with higher levels of humidity and changing precipitation patterns due to climate change often influence this factor as well. However, prolonged periods of drought have been shown to decrease transmission rates, which might negate the increase of transmission due to higher temperatures in some cases (NIEHS 2010).

According to the recently released IPCC 5th Assessment Report on Human Health Impacts, the influence of temperature on malaria transmission appears to be vector specific and non-linear. In general, increased variations of mean daily temperature near the minimum boundary tend to increase malaria transmission. This report also discusses the importance of recognizing lag times according to the life cycle of the vector and of the parasite. A study in central China found malaria transmission to be dependent on average monthly temperature, as well as the average temperature of the previous two months, and the average rainfall of the current month (IPCC AR5 2013). The non-linear aspect of temperature correlation with transmission means that even a small increase in temperature can affect a large increase in transmission, if conditions are otherwise suitable.

In addition to climatic variables, malaria transmission is very sensitive to health interventions and socioeconomic factors. Recent efforts to distribute necessary vector-control measures, like insecticide coated mosquito nets, as well as medication distribution has helped slow these incidence rates. Worldwide, there have been significant advances made in malaria control in the last 20 years (IPCC AR5 2013). The next section of this article will examine some potential solution and mitigation options for preventing further spread of this infectious disease, from both a climate standpoint and from a public health perspective.
What are some possible prevention strategies?

Vaccine Development

The complex life cycle of *Plasmodium* and the variety of factors affecting transmission makes vaccine development for malaria very challenging. There is currently no commercially available vaccine, although over twenty subunit vaccines are presently undergoing clinical trials for safety and efficacy (WHO 2014).

RTS,S/AS01 is the vaccine candidate made by GlaxoSmithKline Vaccines that targets *Plasmodium falciparum*, the most deadly to humans of the family of parasites that cause malaria. A Phase III clinical trial (the last phase of clinical testing, in which the drug is given to thousands of patients that display the disease state to test for safety and side effects) began in May 2009 for this particular subunit vaccine. This trail enrolled 15,460 African children in two age groups: 6-12 weeks and 5-17 months, from seven different sub-Saharan African countries (WHO 2014). The World Health Organization expects the data from this trial to be available sometime in 2014 or 2015. At this time this vaccine will be evaluated for use as a supplemental preventative measure, and is not intended to replace tactics already being used, such as vector control or quinine treatment.

Progress in developing a malaria vaccine has been accelerated in the last few decades, fueled by medical advances and increased funding, as well as an increased transmission rate, which creates a higher demand. The World Health Organization has published the Malaria Vaccine Technology Roadmap, which sets goals to develop and license a vaccine with 50% efficacy and a one year protection by 2015, as well as a 2025 goal of 80% efficacy with a four year protection window (Malaria Vaccine Initiative 2014).

Treatment with Medication

There are a variety of commercially available drugs used for malaria treatment and treatment choices depend on age, severity, which species of *Plasmodium* is causing the infection and whether or not the patient is pregnant. The most common treatments are semi-synthetic derivatives of quinine, which comes from the bark of the cinchona tree in Peru and is pictured below. The history of anti-malarial medication has been marked by a constant struggle between new medication development and the development of resistance to old medications (Mayo Clinic 2014).

Chloroquine is currently considered the best first line defense for malaria and is administered as a three-day course of treatment. This is not ideal, as it is often difficult for health-care workers to follow up with patients in malaria endemic countries, and researchers are working on developing a one-day treatment option. It can also be used prophylactically for travelers going to regions endemic to malaria (Medicines for Malaria Venture 2014).

The ground bark of the cinchona tree is pictured above. The Quechua people would grind the bark and mix with water to relieve muscle spasms and soreness, which was the original medicinal use of quinine.
Other Medications

Another drug that is currently on the market, called Primaquine, is used to treat malaria caused by *Plasmodium vivax*, which has the ability to survive in the liver in a dormant state and cause relapses months or even years later. *Plasmodium vivax* is more commonly found in Southeast Asia and South America than in Africa, and treatment with Primaquine involves a 14-day course of treatment. Primaquine should be avoided in patients with a glucose-6-phosphate dehydrogenase deficiency, as it can cause hemolysis, which can be fatal (Mayo Clinic 2014).

Mefloquine is another drug available for both prevention and treatment of malaria. It is a second-line defense (Chloroquine is first) for malaria treatment and can be used to treat strains of *Plasmodium* that have become resistant to Chloroquine, which is a growing concern. Unlike Primaquine, Mefloquine does not eliminate the parasites in the liver, only in the blood stage, so it should not be used for *Plasmodium vivax* treatment (Mayo Clinic 2014).

A combination therapy known as Artemisinin-Combination Therapy (ACT) is now the standard treatment option worldwide for *Plasmodium falciparum*. Artemisinin was originally isolated from sweet wormwood by ancient Chinese herbalists and used for malaria treatment. Semi-synthetic derivatives of artemisinin are now made in laboratories. When dosed by itself, artemisinin has an extremely short half-life and is quickly eliminated from the body. This is the reason for dosing it in fixed doses with other anti-malarial medications, such as Mefloquine, Primaquine or Chloroquine. The artemisinin component kills the majority of the parasite at the start of treatment, while the more slowly eliminated medications that are dosed with it clear the remaining parasites over time (Mayo Clinic 2014). A mutation on a gene on chromosome 13 in the *Plasmodium* parasite has recently been discovered to be causing resistance to ACT treatment, further complicating the search for the best malaria treatment (WHO 2014).

Mosquito Net Distribution

Perhaps a more achievable form of prevention is vector control, rather than prophylactic medications. According to Nets For Life, an NGO partnership whose mission is eliminate malaria in sub-Saharan Africa, “when insecticide-treated nets are used properly by three-quarters of the people in a community, malaria transmission is cut by 50%, child deaths are cut by 20%, and the mosquito population drops by as much as 90%.” However, it is estimated that less than 5% of children in sub-Saharan African have access to an insecticide-treated net (Nets for Life 2014).

Making these insecticide-treated nets more available to African communities, as well as education programs about the importance of proper use could mean the difference between life and death for millions of African children. NGO’s like Nets for Life and Unicef lead the way in distributing these nets to countries in need and small donations can go a long way in malaria prevention.

The fight against malaria takes off

Mosquito nets sold or distributed in sub-Saharan Africa, 1999-2003 (Millions)

(Unicef 2014)
Indoor Residual Spraying

Another prevention method that has lost some of its popularity since its use in the 1950's and 1960's is Indoor Residual Spraying (IRS) with DDT (dichlorodiphenyl-tricloroethane) insecticide. IRS was the primary control method used during the World Health Organization's Global Malaria Eradication Campaign launched in 1955 (CDC 2014). This method does not prevent people from being bitten by mosquitoes, but attempts to prevent transmission by killing mosquitoes after they have fed.

Indoor Residual Spraying involves coating the walls and surfaces of a house with an insecticide like DDT that will kill any mosquitoes that come in contact with it for a few months. Many malaria-transmitting mosquitoes are endophilic—meaning that they rest inside houses after eating a blood meal. These mosquitoes are particularly susceptible to control with IRS. Killing the mosquitoes before they have a chance to bite another human can greatly reduce the transmission of malaria.

DDT was outlawed by most of the world in the 1960’s for agricultural use due to its deleterious environmental and human health effects. In 2000 the WHO approved DDT for use in IRS and in 2006 began actively supporting its use for malaria control (Malaria No More 2014).

IRS as a preventative tool for malaria lost some popularity when the Global Malaria Eradication Campaign failed to meet its goals and concerns over the environmental and human health impacts of DDT seemed to outweigh its benefits. As the eradication campaign progressed, more and more financial burden was left to endemic countries that could not continue the project. As a result, malaria transmission quickly returned to pre-campaign levels and the IRS technique received negative publicity. However, it has seen recent success in South Africa and may be making a comeback as a preventative method (CDC 2014).

Another issue with the use of DDT and other insecticides as a means of controlling malaria is the rise of resistant mosquitoes. Prolonged exposure to some of the chemical components of insecticides can lead to genetic mutations of resistance factors that get passed on to the offspring of the mosquitoes. This means that the next generation of mosquitoes will be less susceptible to these insecticides, and therefore more likely to be transmitting malaria (see above diagram for areas with resistant mosquitoes).
Source Reduction

Source reduction is the destruction or removal of mosquito breeding sites. The *Anopheles* mosquitoes breed in small pools of water formed from rainfall or irrigation canals. Their larvae develop within a few days and must be mature enough to escape the aquatic breeding grounds before it dries up. The breeding grounds can be destroyed by filling depressions that collect water or draining marshy areas to remove standing water, as well as careful management of irrigation canals (CDC 2014).

In some cases, habitat elimination is not possible, but chemical insecticides or other substances can be added to the larval habitats to stop larval growth. Biodegradable oils can be added to the water surface to suffocate the larvae, as well as specific toxins that only affect insects. Other biological control agents, such as fungi and nematodes that parasitize and kill larval mosquitoes have been used as a form of source reduction, although they are hard to employ in large-scale settings (CDC 2014).

Fogging or Area Spraying

Fogging or area spraying is a technique used to kill mosquitoes in a concentrated area. A machine is mounted on the back of a truck that sprays insecticide into the air in a particular area that is heavily populated with mosquitoes. The timing of the large-area spray must be carefully planned to coincide with peak mosquito activity and must be repeatedly applied to have an impact.

For these reasons, fogging is usually reserved for use only in emergency epidemic situations and its downsides may outweigh its benefits. It is very expensive and may result in the overuse of insecticides, leading to mosquito resistance and other unintended human health and environmental impacts (CDC 2014).
While it is obviously important to develop adaptation strategies to deal with the current impacts of climate change and their implications for public health, it is also important to consider mitigation techniques to lessen the need for future adaptations. Mitigation differs from adaptation in that mitigation address the source of the problem, rather than just the problem, as adaptations often do. There are two ways to go about mitigating carbon emissions: 1) reduce the source (i.e. decrease fossil fuel use and transition to renewable energy use) or 2) increase the sinks (i.e. protect forests to sequester carbon). With the amount of carbon dioxide that humans have already emitted into the atmosphere, there is an inevitable degree of climate change that is sure to happen no matter how much or little carbon we emit in the future. Nevertheless, careful planning to reduce future carbon emissions could prevent potential devastating effects of climate change from occurring, such as the public health impact of malaria epidemics in areas previously unexposed to malaria.

Renewable Development and Fossil Fuel Divestment

One means of reducing carbon emissions is to invest in renewable energy sources. Solar, wind and hydropower energy have come to be at the forefront of alternative energy, along with biofuel and geothermal energy. Each of these options present their own benefits and challenges. One disadvantage is that there often is a rather large up-front investment associated with renewable energy sources that may discourage the public from investing. While it may be cheaper in the short-term to use fossil fuels, the future of a stable planet hinges on our society’s ability to find alternative sources of energy that do not emit large amounts of greenhouse gases into the atmosphere.

The fossil fuels that our society have exploited and taken for granted since the dawn of civilization are limited and increasingly expensive to extract. Yes, it is true that these very same fossil fuels are at the core of our past success and progression of society, including our health care system, and many of the impacts we are now realizing were not foreseen. But now that we know the potential impacts from the continued use of fossil fuels, why not invest in renewable energy sources now, before it is too late? Renewable energy development could stimulate the economy, create jobs and save consumers money in the long run. Divestment from fossil fuels is a crucial part of climate change mitigation that will inevitably happen sooner or later when there is no more oil to be drilled, but why wait until that happens when it could jeopardize the quality of life for generations to come?
Collective Action

There are many challenges that will need to be overcome to provide society with non-fossil-fuel intensive health care needs, including malaria treatment and prevention. These challenges are complex and global cooperation will be essential if we hope to overcome them. One of the hardest obstacles to overcome when thinking about solutions to climate change is that it is truly a global issue. One person, one state, or even one country is not going to be able to single-handedly solve climate change, even with all the resources and money in the world. It is going to take cooperation with all nations of the world, especially the big carbon emitters, who are usually the ones unwilling to compromise in international climate negotiations if we hope to reduce emissions before it’s too late.

Individual efforts to reduce consumption, increase household energy efficiency, buy local products with minimal packaging, purchase green energy if possible, ride a bike instead of driving, or even just having intelligent conversations with peers about climate change will all help to put pressure on our governments to take the plunge towards the policy changes that need to happen to cut ties to fossil fuels and slow global warming. Actions towards climate change mitigation will buy some time for those people at risk for malaria to get the aid they need to control mosquitoes and the infectious disease.

Collective action to drastically reduce carbon emissions and transition towards clean and renewable energy will call for large-scale policy and infrastructure changes in developed countries like the United States. Perhaps more importantly, a core cultural ideology and worldview shift will also need to happen if we hope to reverse the ramifications of our consumption habits from the last few hundred years. As American author Wendell Berry once aptly wrote, “...the care of the earth is our most ancient and most worthy and, after all, our most pleasing responsibility. To cherish what remains of it, and to foster its renewal, is our only legitimate hope” (The Art of the Commonplace: The Agrarian Essays 2003).

Conclusion

It is not too late or too difficult to address malaria resurgence and other climate change-induced public health impacts, but before society can begin to address a problem as complex as climate change, a reprioritization of morals and ideologies needs to occur. A shift from our current focus on an ever-expanding economy and increasing profit margin, no matter what the cost to the environment or the countries most vulnerable to climate change, to a focus on sustainability and a sense of gratefulness for what the Earth provides needs to occur in order to address climate change, both for the people dealing with its effects as we speak, and for generations to come.

Another important point to keep in mind is that before throwing new technology at the problem, it is important to fully understand the impacts and potential ramifications of this new technology. Researching the long-term effects of a new technology can be time-consuming and expensive to conduct, but is a very important step in determining the safety and efficacy of that potential solution. One of the reasons the spread of malaria is so difficult to control is because there are now DDT-resistant mosquitoes from the overuse of insecticides, on top of quinine-resistant Plasmodium, caused by improper medication use, so both the vector and the bug are becoming harder to kill. The most unobtrusive solutions sometimes turn out to be the best options, if it means there will be less unwanted side effects years down the road.

While addressing climate change and its related public health impacts seems daunting, it is not impossible. With global cooperative, existing technologies and a collective desire to improve the living conditions of those affected by climate change, the spread of malaria could be slowed, and even the disease eradicated, for the benefit of future generations.