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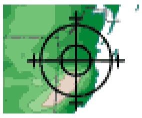


MAPPING MALARIA

BY JOHN WEIER • DESIGN BY ROBERT SIMMON

In a cluttered lab, surrounded by plastic containers fraught with hovering mosquitoes, epidemiologist Don Roberts pointed to a small, beat-up slide projector. The picture on the screen appeared to be nothing special — a satellite photo of a village littered with blue, orange, and yellow dots.

Yet, for Roberts and anyone who knows his work, this image represents one of the largest health problems in the world as well as a possible solution. He explained the photo was of a typical village in Belize. Most of the houses there have dirt floors and thatched roofs. The people are extremely poor and bathe and wash their clothes in the river. And for the last ten years, at least, they have been hit with periodic malaria outbreaks that sap their livelihoods.

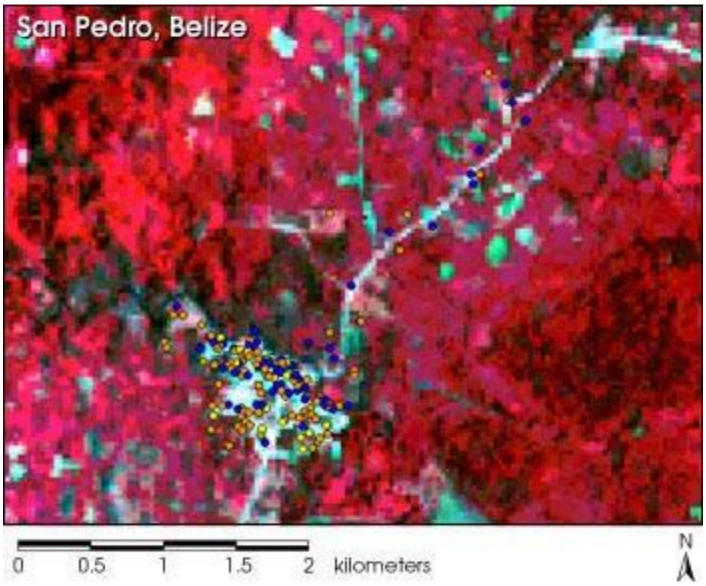
The reason malaria is so bad in these villages, Roberts said, is that the no one in Belize has the resources to combat the problem. Using methods available today, the government would have to send people out into the countryside every six months and spray nearly every house with insecticide to keep the disease at bay. Like most third world countries with chronic malaria, they simply do not have the budget.

However, the key to this problem may lie in the yellow dots on the photograph. "Over fifty percent of malaria cases in this village are represented by those yellow dots. As you can see there aren't many," said Roberts. "Less than fifteen percent of the houses." By spraying just these houses with insecticide that repels the mosquitoes, the village could rid itself of over half of its malaria problem. He said this slide represents a pattern all over Belize and perhaps the rest of the world.

For the past fifteen years Roberts and a group of scientists at the Uniformed Services University and NASA have been working on a system to pinpoint houses and areas at high risk for the disease. Using medical databases of malaria, airplane photographs, and even remote sensing satellites, they have laid the groundwork for the system. By predicting this risk, the cost of spraying houses and the amount of chemicals used in any given country would both drop dramatically. Yet, efforts to ban spraying may prevent him or these countries from ever getting a chance.

A Mayan household in Belize, Central America. In tropical and subtropical regions around the world, most of them poor, malaria has again become a major killer. Research using remote sensing data by scientists at the United States Uniformed Health Services promises to reduce the threat of this resurgent disease.

A researcher stands in his lab surrounded by mosquitoes—the carrier of the disease malaria. (Photographs courtesy Dr. Donald Roberts, Uniformed Health Services)



Malaria cases per house

- 0
- 1-5
- 6-14

This image taken over San Pedro, Belize, by a Landsat satellite, shows the distribution of malaria cases in the area. The yellow and orange dots show where most outbreaks occurred per household. The vegetation in the surrounding countryside is colored red in this image, while human settlements and roads are light blue. (Image courtesy Uniformed Health Services)

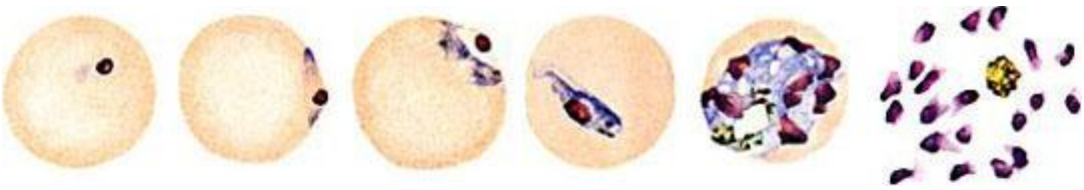
An Unending Epidemic

Malaria, unlike most major diseases around in the 19th century, has not steadily declined throughout this century. Though malaria was largely suppressed throughout the world in the 1960s and 1970s, it sprang back with a vengeance over the last fifteen years. The number of reported cases has almost doubled, making it the third largest infectious disease in the world. Scientists estimate that last year alone upwards of 300-500 million people contracted malaria and well over a million people, mostly children, died from the disease. (World Health Organization, 1999)

Malaria parasites are transmitted to humans by mosquitos. A mosquito ingests parasites when it bites an infected person, and will infect anyone it bites later. The cycle of malaria transmission can be broken by killing mosquitos in epidemic regions, or reducing the number of hosts of the disease. (Photograph copyright BIODIDAC, University of Alberta)

For those areas affected by the disease, the economic impact is enormous. Each time a person gets the disease they can expect to miss 5-20 days of work, and chronically infected families on average lose more than twenty five percent of their yearly income. In the countries where the disease is a nationwide epidemic, malaria patients occupy 3 out of 10 hospital beds, and the net effect can be a 5 percent drop in the nation’s Gross National Product. Collectively, the direct and indirect costs of malaria for these mostly poor, third world countries are well over $2 billion a year. (World Health Organization, 1998)

The main reason malaria is so hard to control has to do with the nature of the disease and the way it is spread. Malaria is neither a virus nor a bacterium, but a one-celled parasite. The parasites breed in and are transmitted by mosquitoes. When the mosquito bites a person, the parasites get into the new host's bloodstream through the mosquito's saliva. From there the parasites head directly for the liver. To insure their success in infecting the human body, they further multiply in the liver cells for 9 to 16 days. They then pour out into the blood stream and begin feeding on red blood cells. (World Health Organization, 1998)



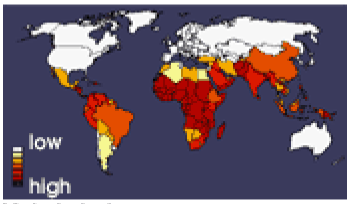
From left to right, increasingly mature malaria parasites. These parasites grow in red blood cells, progressing through several stages of maturation, until they rupture, spreading more parasites throughout the victim. (Illustrations from Coatney GR, Collins WE, Warren M, Contacos PG. The Primate Malarias. U.S. Department of Health, Education and Welfare, Bethesda, 1971)

To date there is no reliable vaccine for any type of parasite. The genetic code of parasites is much more complex than most viruses or bacterium. The malaria bug adapts quickly to vaccines and even some cures, and the human body develops a partial resistance to the disease only after repeated attacks. There are drugs such as quinine and chloroquine that kill the parasites once they have infected a person, but these chemicals are expensive and people must take them continuously to stave off the disease. (Shell, 1997)

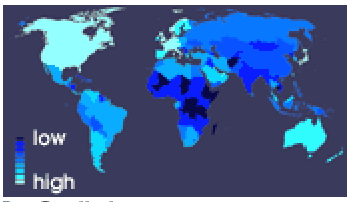
Another problem with malaria is that it uses the mosquito as a delivery system. Even when a malaria victim is isolated, the disease can carry on. Often people don't even know they have it. Since the parasite runs rampant in the bloodstream, symptoms can include everything from muscle ache, to fever, to jaundice to dementia. In mild cases many just chalk the disease up to the flu and do not seek treatment at all. (Shell, 1997)

Like A Surgeon's Knife

"If people weren't poor we wouldn't have malaria," said Roberts. One only needs to look at a global map of malaria outbreaks to get an accurate depiction of where the standard of living is low. Outbreaks blanket Central Africa, India, Pakistan, and Southeast Asia. In the Western Hemisphere, a large epidemic exists over the Brazilian rain forest. From there the disease winds its way up through Central America and into Mexico, stopping a few hundred miles south of the United States, which was also covered with the disease not more than sixty years ago. (World Health Organization, 1998)



Malaria Index



Per Capita Income

Poor nations are affected disproportionately by malaria. People who can not afford air conditioners and tightly sealed houses are susceptible to mosquito bites, and those who can't afford expensive anti-malaria drugs are potential reservoirs of the disease. (Maps from Roll Back Malaria, World Health Organization)

The reason malaria infects impoverished areas, Roberts asserted, has little to do with hygiene, the water supply or a bad diet. Rather, it has to do with the lack of protection impoverished people have against mosquitoes. The Anopheles mosquito breeds in standing water, is most active at night and usually bites people as they rest in their homes. In poorer areas of the world, drainage systems are usually substandard, so these types of mosquitoes breed in droves. Once the larvae reach the adult stage, villagers have no way to keep them out of their houses. Most houses in these areas do not have air conditioners or screens, and some just consist of a thatched roof and a dirt floor. These people cannot afford bug repellents or nets. As they eat or sleep, the mosquitoes come and go as they wish.

"But Malaria is a preventable disease," Roberts said, "The reason it is not prevented is money, and a commitment on the part of the governments to protect the people." In the past, people have suppressed malaria by spraying DDT (dichloro-diphenyl-trichloro-ethane) or other less effective, repellents on houses. The sprays kill or keep the mosquitoes out of the houses at night when they bite. However, implementing such a program requires the chemicals and hundreds of workers to distribute them; and spraying houses once is not a permanent solution. To really put a damper on malaria, houses must be sprayed annually, said Roberts. Some governments are too poor to sustain such a program with no outside help. Other governments simply do not care. Generally, the more unstable a government is, the worse malaria epidemics become.

Roberts and his team began their project fifteen years ago to help those governments with good intentions, but a lack of funds. They based their research on the idea that vector-borne diseases have definable determinants that can be mapped. As most diseases spread, they generally follow the economic, political, racial and even sexual boundaries of our society. Tuberculosis, for instance, infects areas where people have poor hygiene and medical facilities. Hepatitis C reaches new victims through blood transfusions, sex and shared needles. Those who live at the edge of a forest are at no greater risk than those who live near a swamp or desert. The local terrain and climate make little difference.

Vector diseases, on the other hand, are transmitted by insects and animals, which live, feed and reproduce in specific environments and have unique ways of coming into contact with people. While socioeconomic factors can still play a role, the risk of getting infected ultimately comes down to a person's exposure to the disease-carrying creature's environment. Scientists can map the risk factors for a vector-borne disease as they would map a flood plain or a forest.

The larvae of *Anopheles vestitipennis,* a potentially important vector of malaria, occur in cattail marsh habitats. Houses, like those visible in the background, are frequently constructed in close proximity to these mosquito habitats. (Photograph courtesy Dr. Donald Roberts, Uniformed Health Services)

Using modern technologies such as remote sensing satellites, Roberts' team planned to identify the environments in which mosquitoes breed and those homes where occupants are most prone to contracting malaria. "The way we wanted to use these technologies was like a surgeon's knife. We wanted to go target houses according to their risk," he said. With such a system, nations could then cut the disease off at the source simply by spraying those houses and areas that have the greatest risk of infection. This strategy could avoid the monetary and environmental costs of spraying every village in the country.

For the past fifteen years, since the project began, the scientists have conducted most of their research in Belize with the help of NASA grants and the full support of the Belizian government. At the center of their research has been an effort to understand the patterns of past malaria outbreaks. The Belizeans set up a national malaria database containing the names and addresses of every reported malaria case in Belize. Roberts' team then assisted the government in looking for trends in the database.

They found that the risk of malaria in each house is pretty much constant over time. Certain houses, due to their location, their construction and a number of other factors, have a disproportionate number of malaria outbreaks. In fact, more than fifty percent of malaria cases in most villages occur in less than fifteen percent of the houses. Knowing this, Roberts' team developed a system to categorize these houses in terms of the number of malaria outbreaks they've had. By spraying these houses alone, Roberts explained, Belize can rid itself of most of its problem. "If you have a house or an area that is producing a large number of malaria cases, that house becomes the source of infection for many other people in the neighborhood," he said.

Spotting Infection

A national malaria database cannot predict all the areas that are having problems. The population in Belize, like that of most third world nations, is expanding at an exponential rate and people constantly erect new houses. Moreover, many people do not report the disease when they get sick because it is hard to diagnose on sight.

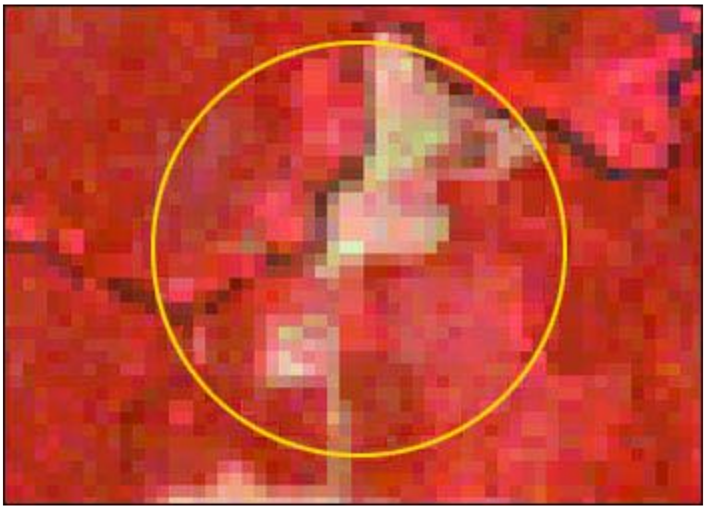
Satellite imagery allows scientists to map the environment. Regions that flood seasonally, or have standing water, are good breeding grounds for mosquitoes. The yellow circle in this Landsat image indicates an area around a cluster of houses with multiple malaria cases, and was used to generate a landcover map. (Image courtesy Uniformed Health Services)

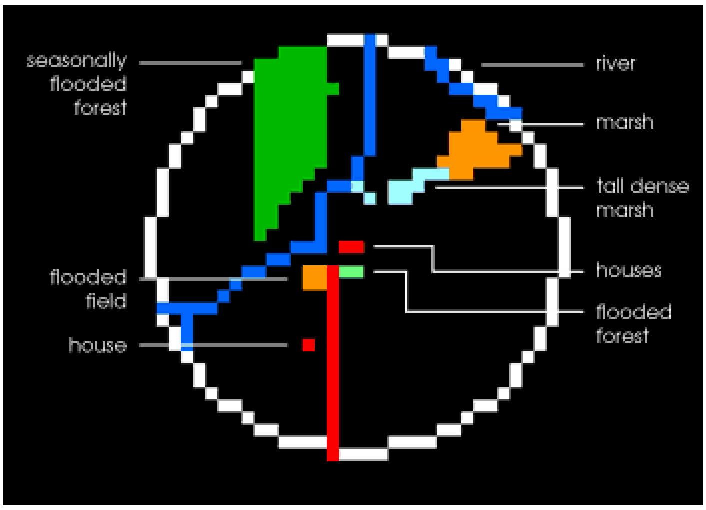
To augment the database, the researchers have been working to create satellite maps of Belize that highlight the areas where the major malaria-carrying mosquitoes breed. With such maps, the government could identify regions of potential risk where there aren't many records. Since satellite maps can be updated on a regular basis, Belizians would also be able to gather information on land use, land cover, where people are and what new developments have taken place.

Creating a system to map Belize's mosquito-ridden areas is far more complicated than manipulating a database. The first step involved identifying the types of environments in which each species of mosquito thrives. To find where these mosquitoes breed best, the Uniformed Services team went out into the wetlands and rivers of Belize and took samples of the various species of mosquitoes and their larvae. They looked for correlations between habitat variables, such as types of plants and water depth, and the number of mosquitoes and larvae present. Generally, the diet of the male mosquito determines the type of vegetation a species prefers. Water, shade and protection from predators are also factors. (Rejmankova et al., 1998)

With the exception of one river species, the team determined where all the major malaria carriers breed. They found that *Anopheles albimanus* is abundant in reed marshes with flooded mats of blue-green algae. (Montgomery et al., 1996) The *Anopheles punctimacula,* on the other hand, breeds best in swamp forest with lots of rotting organic matter in the water. The *Anopheles vestitipennis* were found in both swamp forests and in reedy marshes. (Rejmankova et al., 1998)

The next step was to locate these areas with a satellite imaging system. The Uniformed Health Services team used data from Landsat 5 and the French Systeme Pour l'Observation de la Terre (SPOT) in their work. Both of these satellites move in approximately circular orbits nearly pole to pole around the Earth, scanning strip after strip of our revolving planet. The SPOT satellite retrieves images of the planet's land surfaces every 26 days, while Landsat 5 collects images of a given location on land roughly every two weeks. These satellites are sensitive to different wavelengths of radiant energy—ranging from visible to infrared light—reflected and emitted off of the Earth. The images are then radioed back to the surface in the form of data, where Montgomery, Roberts and other researchers can extract valuable information from them.





The data contained in the image to the left was used to generate the map of landcover types below it. The highlighted areas (marsh, flooded forest) are likely filled with mosquitoes. Scientists use these maps to locate houses and communities that are exposed to large numbers of mosquitoes. They then know where to allocate resources for mosquiot control, including insecticides and bed nets. (Images courtesy Uniformed Health Services)

"With these satellites, [scientists] can essentially look for the reflectance values, or spectral signatures of each of the types of habitats," said Brian Montgomery. He's a remote epidemiologist at NASA's Goddard Space Flight Center who worked for Roberts during the early 1990s. In very basic terms, the researchers locate an area on an image of Belize that they know, for instance, contains marshes with blue-green algae. Using computers, they then identify those specific colors that distinguish this type of marsh or wetland from anything else covering the ground. They can then take this color combination and apply it to uncharted areas of Belize to find other reed marshes with blue-green algae. Similar classifications can be done with all the basic ground covers—cropland, urban areas, forest swamp, rivers and roads. The end result is a satellite map showing a wide range of land covers and mosquito habitats across large areas of Belize. (Roberts et al., 1996)

However, alone this image would just appear to be a collage of colors covering the ground. To get an accurate mosquito habitat map with crisp outlines of swamps, villages, rivers and roads, the scientists have to combine the multi-spectral image with other sources of information, Montgomery said. The researchers bring together the imaging data along with maps of the area, aerial photographs, ground survey information and even information on housing construction. They then use GIS (Geographic Information System) software to integrate all of these layers of data to form a coherent map of the landscape, complete with the location of the villages at risk and the habitats of various species of mosquitoes. "Anyone using these maps should be able to tell with high accuracy, the precise longitude and latitude where risk for malaria is high," said Montgomery.

A Valid Solution In Jeopardy

Roberts said that their preliminary results are promising. The experimental maps have been 90 percent accurate in predicting the presence of mosquitoes in an area when the scientists know what they are looking for. With about three more years of research, they will be ready to apply these maps. There are still a few kinks they have to work out. No one knows, for instance, specifically where the malaria-carrying *Anopheles darlingii* mosquitoes breed. More tests need to be run to determine the exact correlation between mosquito numbers and malaria outbreaks.

Larvae of *Anopheles darlingi* (another important vector of malaria in Belize) are found in river habitats. Villages and individual houses are commonly associated with rivers, as depicted in this aerial view of the Sibun River. (Photograph courtesy Dr. Donald Roberts, Uniformed Health Services)

The maps should be useful by themselves for warning the government of potential malaria outbreaks in newly-settled areas.

Ultimately, the scientists would like to combine this mapping system with the database of houses at risk. "We would match the map up with the national malaria database to determine how many malaria cases occurred over the last ten years. We would bring all of those elements of data together to begin targeting houses for spray," Roberts said.

The final product would resemble the slide of the Belizian village Roberts displayed in his lab, except the homes identified within the database would be accompanied by highlighted areas where the mosquitoes live. Not only would the government spray the highly infectious houses, but those closest to mosquitoes' breeding habitats as well.

Within five years the scientists will have everything in place and begin field testing the model on individual villages. From what he's seen so far, Roberts is confident this method would work on a nationwide scale. By spraying roughly 3,600 houses, Belize could both reduce a majority of its malaria problem and amount of labor and insecticide used. The Belizian model could also be used as a blueprint for other countries in Central America, Asia and Africa. These nations would still have to determine the habitats of the mosquito species in their part of the world and build a database, but with Roberts's study as a model, they would know what to do to and how to make it work without much waste.

Roberts' biggest worry now, however, isn't that his system will be useful. His biggest fear is programs underway by the United States and other wealthy nations to ban the use of DDT around the world. Roberts argued that there have been many studies comparing chemical irritants and repellents, and DDT is the only one that is known to repel mosquitoes throughout the evening. It is also the only one that most small governments can afford to buy in bulk.

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