Environmental Determinants of Vector-borne Disease

The distribution of vector-borne diseases such as malaria is, in part, related to environmental factors such as the presence or absence of wetlands, the weather, and the type of surrounding vegetation, elevation, and so forth. Many of these environmental factors can be mapped using remotely sensed data. Some of the environmental variables that control vector-borne diseases are still not well understood. For instance, different mosquito species prefer different breeding habitats, and some species are more efficient vectors of malaria than others. Once the environmental factors are understood, remote sensing can be used to target the at-risk areas for spraying or other preventive measures. Targeted programs save limited prevention resources and are particularly helpful for poor countries.

NASA, the Uniformed Services University of the Health Sciences, the University of California, and others are collaborating on several research projects to study the environmental determinants of vector-borne diseases. Projects include:

1) Using remote sensing to estimate the area of mosquito larval habitat in Korea for calculating the cost of control programs
2) Determining the distribution and land cover types associated with Bartonellosis in Peru
3) Using remote sensing and GIS to study the marshes, rivers and other environmental determinants of malaria in Belize
4) Relating the distribution of malaria and mosquitoes in Thailand to remotely sensed environmental factors.

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Remote Sensing for Malaria Prevention in Korea

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After being absent from the Republic of Korea since the 1970's, malaria (*Plasmodium vivax*) re-emerged with the occurrence of 2 cases in 1993. The number of cases has increased almost every year since. The focus of the disease has been just south of the Demilitarized Zone (DMZ) between the Republic of Korea (ROK) and the People's Democratic Republic of Korea (PDRK). From 1993 through December 2000, more than 3,700 cases of malaria were confirmed with more than 1% of the cases occurring in U.S. military personnel stationed in the Republic of Korea (Preventive Services Directorate, 18th Medical Command, Seoul, ROK; personal communication).

US Army personnel stationed near the Demilitarized Zone (DMZ) currently use chemo-prophylactic drugs and other preventive measures such as insecticide-impregnated bed nets and topical repellents. The use of larvicides in the rice paddies and ponds surrounding the military bases is another option. The purpose of this study was to estimate the area covered by mosquito habitat using Landsat and Ikonos data for two U.S. military bases in Korea. The area estimates of mosquito habitat are then used to estimate the cost of larviciding near U.S. military bases.

Fieldwork for this project was performed from June through September 2000, and concentrated on two military bases near the DMZ: Camp Greaves and Camp Casey. Camp Greaves is located in a rural area just south of the DMZ. Camp Casey is approximately 35 miles east of Camp Greaves and is in a more populated area with less agriculture. Standard larval survey techniques, using a plastic dipper in all types of standing fresh water, were done at both sites.

U.S. military and civilian entomologists, Col. Terry Klein and Dr. Donald Roberts, collecting mosquito larvae in a river near a U.S. military base.

Seven types of larval habitats were identified and sampled:

1) rice fields
2) streamside pools
3) irrigation ponds
4) irrigation ditches
5) drainage ditches
6) swamps
7) rivers

Irrigation ponds, though small, were found to have high densities of mosquito larvae. Because of the large area covered by rice fields and their proximity to military bases, rice fields are also a very important habitat.

Photo taken from a medical helicopter over one of the U.S. military bases in South Korea. Military base is in the center of the photo. Notice the rice fields adjacent and behind the base. River next to the base also provides mosquito larval habitat. Poles in the foreground are stretchers, part of the standard equipment on a medical helicopter.

Two images were used for this study, a Landsat image acquired on April 29, 2000, and an Ikonos image acquired on August 2, 2000. The Landsat image covers both the Camp Greaves and the Camp Casey site. The Ikonos image only covers the Camp Greaves site. The images were geo-referenced to a UTM projection and a WGS-84 datum.

A parallelepiped algorithm was used to perform supervised classifications on the Ikonos and Landsat images. For the Ikonos image, training sites were collected for the river, ponds, ditches, and rice fields**.** Because of the lower resolution, training sites on the Landsat image included only rice fields and the river; ponds, and ditches were too small to be resolved. Other non-habitat areas of the images also were classified as urban and forest, but these were later grouped together as a single, non-habitat class for the purpose of estimating area.

Because of the interest in estimating the amount of larval habitat in areas that would affect the camps, 1-kilometer buffer zones were created around the two camps using Arc/Info software. A program was used to generate reports on the area covered by each class in the classified image. Another program was used to compare the Landsat and

Ikonos classifications on a pixel-by-pixel basis and create a new image that depicted matching and non-matching pixels.

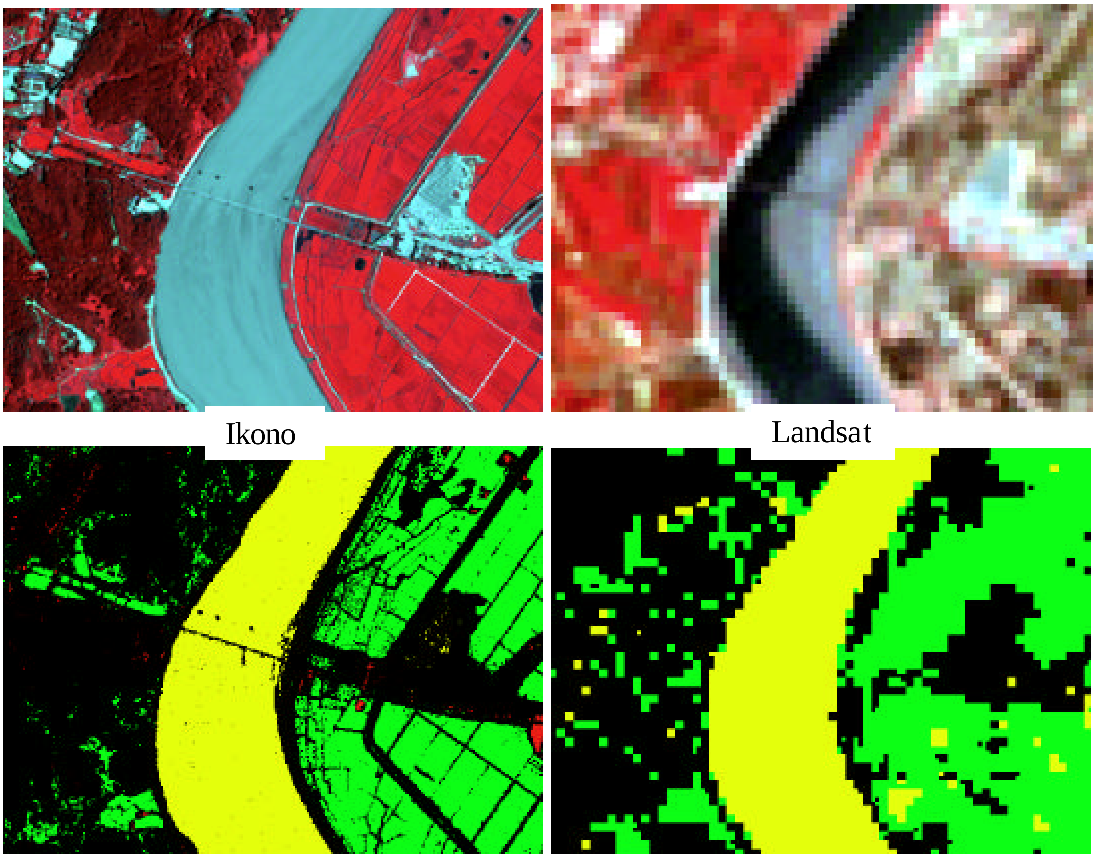

Figure 1: IKONOS (left) and Landsat (right) images in false color (top) and classified (bottom) view showing vector habitat and non-habitat areas. The difference in detail is due to the difference in resolution of the two images, IKONOS has 4-meter pixels, Landsat has 30 meter. In the classification, river is shown in yellow, rice fields in green, irrigation ponds in red. Because they are small, irrigation ponds could not be classified on the Landsat image.

Figure 1 shows the result of the classifications of the Landsat and Ikonos images. Rivers, ponds and rice fields were successfully classified on the Ikonos imagery. Ditches could not be successfully classified on the Ikonos imagery, possibly due to the trees; shrubs and other vegetation that grow along the ditches and make them spectrally similar to other land cover classes. On the Landsat imagery, rivers and rice fields could be classified, but ponds and ditches were too small and could not be used for collecting training sites. A visual comparison of the Landsat and Ikonos classifications, shown in the figure, shows that the two are quite similar in the classification of the river. However, small rice fields were not as accurately classified on the Landsat classification.

A comparison of the Landsat and Ikonos classification was done using a program to compare the classifications on a pixel-by-pixel basis.

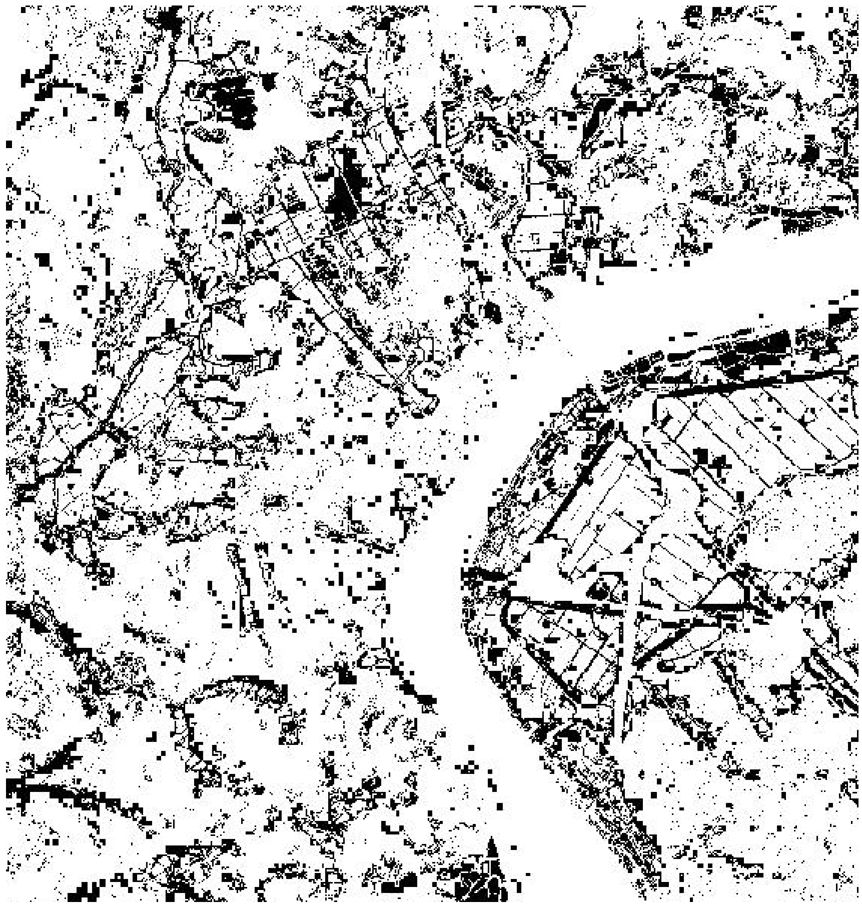

***Figure 2**:* Result of a pixel-by-pixel comparison of Ikonos and a Landsat classification results. Black pixels (20.63% of the image) represent disagreement in the classifications. White pixels (79.37% of the image) represent agreement. Disagreement is mostly due to differences in the resolution and the acquisition dates of the images.

The white pixels in Figure 2 represent the pixels that were classified the same on the two images; black pixels were classified differently. A 79.37% agreement in classification was found between the Landsat and Ikonos classifications. Differences in the two classifications are due to differences in the acquisition date of the scene and the resolution of the image.

Area estimates for the buffer zone around Camp Greaves are shown in Table 1. Although the difference in the classification of Landsat and Ikonos images was approximately 20%, the area estimates were very close.

Table 1: **Comparison of Land Cover Estimates (m^2) for Camp Greaves**

	Ikonos	Landsat
Rice fields	4,198,151	4,304,250
Ponds	48,709	n/a

Although similar land cover area estimates of mosquito larval habitat can be obtained from Ikonos and Landsat imagery, the use of Ikonos has the advantage of being able to portray and classify small land cover features such as ponds and rice fields less than 30 by 30 meters in size. Although ponds represent a relatively small portion of the total habitat area, they are an important breeding habitat for mosquitoes since they contain higher larval densities than the rice fields late in the growing season

The habitat land cover estimates were used to estimate the cost of mosquito larviciding around the camps (Table 2). For Camp Greaves, which has fewer soldiers and more habitat area, the cost of chemoprophylaxis is less than the cost of larviciding. For Camp Casey, which has more soldiers and less larval habitat, larviciding world be a cost-effective option. Although cost is not the only consideration, this type of analysis can provide information to help public health officials make decisions.

Table 2: **Cost comparison of chemoprophylaxis to larviciding for control of malaria in South Korea**

Camp Greaves	Camp Casey
430.4 ha of habitat	122.5 ha of habitat
Larvicide treatment = $40,263.13	Larvicide treatment = $11,450.37
Chemoprophylaxis = $28,522.80 cost for 760 persons	Chemoprophylaxis = $330,264.00 cost for 8000 people

Remote Sensing and GIS Studies of Bartonellosis in Peru

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Bartonellosis is a bacterial disease endemic to the Andes Mountains that occurs in two phases. In the first phase, fever and anemia can lead to coma and death. If the victim survives the first phase, blood-filled, wart-like skin lesions appear and can last for many months if not treated. Although treatable with modern antibiotics, the disease still claims lives in remote areas without medical care and among those who delay medical care due to inability to pay.

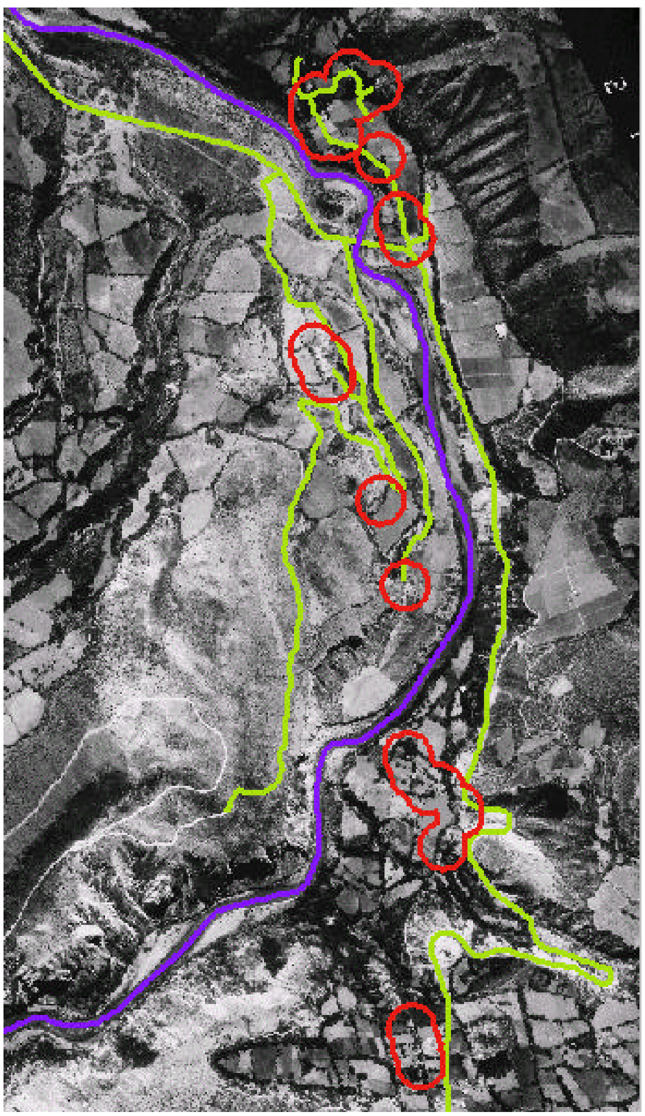
Sand flies have been incriminated as the vectors of bartonellosis. Breeding places of sand flies are difficult to find and are typically under stones, in masonry cracks, in poultry houses or other areas combining darkness, humidity and a supply of organic material for food. Breeding sites are never aquatic. Adult sand flies generally rest in protected situations during the day, but leave these shelters at night to seek a blood meal.

A study of the disease led by USUHS has been on-going for the last 5 years and includes medical, epidemiological, entomology, and animal studies.

Study participants being interviewed by a local Peruvian nurse
as part of the bartonellosis study in Caraz, Peru.

The Laboratory for Terrestrial Physics has participated as part of this larger investigation by contributing remote sensing and mapping. Remotely sensed images are used to map houses in the study area. Maps of houses are important to the field teams since there are no large-scale maps of the area. Maps and satellite images are used to determine the distribution of the disease and the environmental factors that may influence the abundance and distribution of sand flies.

Several conclusions have been drawn from the remote sensing work to-date. Bartonellosis has been found to occur primarily in agricultural areas. The incidence of disease is low in urban areas. The disease does not occur more frequently near rivers. The disease tends to occur in clusters perhaps due to what is now thought to be the mechanism of the spread of the disease, person to sand fly to person, with no intermediate host.



Aerial photograph of a village in the Andes Mountains of Peru. Red lines represent 60-meter buffer zones around houses testing positive for cases of bartonellosis. Notice the clustering of cases. Blue line is the river. Green lines are roads. This image was created by Judith Chamberlin, a student in a course taught by NASA at the Uniformed Services University of the Health Sciences.

We are currently testing the idea that the distribution of the disease might be determined within the agricultural areas by land cover type. A preliminary examination of positive and negative case houses with a Landsat unsupervised classification showed an association of positive case houses with one agricultural land cover class in the Caraz area. However, no association was apparent using high-resolution Ikonos images for the Cusco area. The Caraz study will be redone using a high resolution Ikonos satellite image and additional disease data, recently collected.

Environmental Determinants of Malaria in Belize

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Don Roberts, (USUHS)
Richard Andre (USUHS)
Shilpa Hakre (USUHS)
Nicole Achee (USUHS)
Dr. Vanzie and Palanco (Belize Ministry of Health)
Andrew Au (Raytheon Service Company in support of Goddard Code 926)

This project studies how human-induced change in Belize and natural factors affect the breeding habitats of mosquitoes and the distribution of malaria. Malaria is an on-going problem in Belize, a small country in Central America. Projects, which improve the understanding of the distribution of malaria in Belize, benefit the country by allowing it to allocation scare resources for malaria control in the areas that will benefit the most. Understanding if human-induced land cover change affects mosquito populations, may be an important factor in malaria prevention in this country.

Three main hypotheses are being tested:

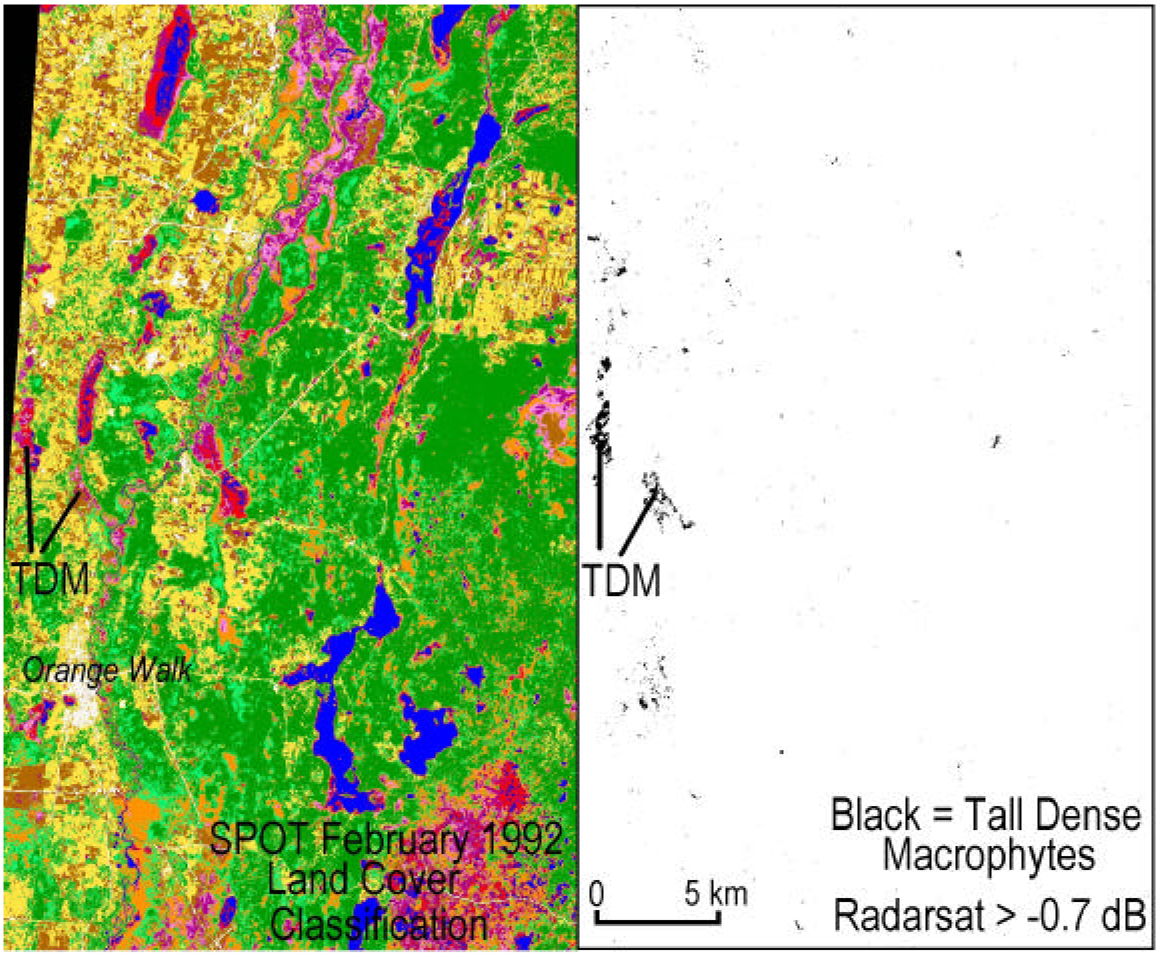
1. Increased phosphorus from the runoff from agricultural land into the marshes increases the amount of tall dense macrophytes (cattails), which serve as a breeding habitat for the most efficient malaria vector species in Belize.

2. The distribution and incidence of malaria within the villages of Belize is influenced by weather, land cover including water bodies and vegetation type, and topography.

3. Removal of forest along streams allows the growth of bamboo that provides more vector habitat in the form of floating debris in the streams.

Hypothesis 1:
Phosphorus from the runoff from agricultural land into the marshes increases the amount of tall dense macrophytes.

In order to map the distribution of tall dense macrophytes (TDM) and the surrounding land cover of the marshes, SPOT images and Radarsat images were acquired and co-registered to 1:50,000 scale topographic maps. Kevin Pope (Geo Eco Arc Research) processed the SPOT and Radarsat images to create a classification map showing the marshes, the TDM, and other land cover.



SPOT land cover classification (left) created using an isodata unsupervised classification program and radarsat image (right) processed using a threshold algorithm. Although tall dense macrophytes (TDM), or cattail marsh, could not be classified separately on the SPOT image, the high radar return allows it to be mapped on the radar image. On the SPOT classification, blue=water, red=low marsh, purple=medium marsh, pink=high marsh, green=forest, yellow-brown-orange=agriculture, white=urban or bare ground. Processing by Kevin Pope, Geo Eco Arc Research.

It was found that while SPOT did an excellent job of classifying the marshes overall, only Radarsat was able to identify the TDM marsh due to the corner reflector characteristics exhibited by the TDM. After trying several processing methods, it was found that a simple threshold algorithm is the most useful for extracting the higher reflectance TDM marshes from the Radarsat image. A number of TDM marsh locations mapped by Radarsat were verified in the field in April.

In order to select marshes for transect sampling and to determine the spatial relationship between TDM marshes and land use, further analysis was done by the LTP on the classification maps. A separate image was made containing only the marsh pixels from the classification. The marsh image was then filtered using a 7 by 7 mode filter to remove the noise and the very small marshes from the image. Seventy-seven marshes were selected to be used for further processing and as possible transect sites in the field. The 77 marshes all contained TDM and included both marshes surrounded by agricultural fields ("impacted marsh") and marshes that were completely surrounded by forest ("pristine marsh").

To create a report of the land cover types for the 77 marshes, further processing was necessary. The filtered marsh image was converted to a vector format. Each marsh was extracted into a separate vector segment and buffered 12.5 meters outside of the marsh. A report was created for each marsh and its surrounding buffer zone that listed the square meters of each land cover type for the marsh. The data were entered into a spreadsheet program and the percent of agriculture, forest and TDM for each marsh was calculated. In order to compare the amount of TDM for "pristine" and "impacted" marshes, the percent agriculture and forest versus the amount of TDM was plotted. There was no correlation between the amount of TDM and the surrounding land cover type.

The lack of correlation between the amount of TDM and the presence or absence of agriculture seems to disprove the hypothesis that increased phosphorus from agriculture promotes the growth of TDM. However, we have not yet examined marshes without TDM. There may be a correlation between the presence versus absence of TDM with agriculture. This possibility will be examined in the coming year.

Hypothesis 2:
The distribution and incidence of malaria within the villages of Belize is influenced by weather, land cover including water bodies and vegetation type, and topography.

A national GIS is being developed by Shilpa Hakre, a USUHS graduate student, with help and advice from Penny Masuoka (USUHS, in support of Goddard Code 920) and Andrew Au (Raytheon Service Company, in support of Goddard Code 926). The purpose of the GIS is to study habitat distribution, land cover, weather, topography and malaria incidence on a regional scale. GIS data of rivers and settlements (villages) were obtained from the Belize Land Information Centre (LIC). The settlement data have been combined with information from the Belize national malaria database and the national census to create a GIS of malaria incidence for 150 villages. Maps of the spatial distribution of malaria incidence from this GIS show that malaria incidence increases in southern Belize.

River data obtained from the LIC are being processing with other data in the national GIS in a couple of ways. A program was run to give the distance from each village to the nearest river. These data will be analyzed with the mean malaria incidence for each village to determine the relationship between the two. The total length of streams within a buffer around each village will also be analyzed.

A Landsat mosaic of Belize and a vegetation map are being used to obtain the land cover types for each village. A 1-km digital elevation model was downloaded from the Internet and slope was calculated for the country. A value for slope and elevation will be extracted for each village.

Since weather events can affect malaria incidence, a retrospective study of the weather in Belize is also being done. A graph of the malaria incidence data on a month-by-month basis showed that the incidence of malaria increases for some districts during the rainy season. To further explore this relationship, we have obtained temperature and precipitation data for 20 weather stations in Belize. These will be put into the GIS and interpolated to obtain raster images of precipitation and temperature. The weather data will be added to the national GIS and compared to the malaria incidence for villages.

Hypothesis 3:
Removal of forest along streams allows the growth of bamboo that provides more vector habitat in the form of floating debris in the streams.

Bamboo leaves form mats of floating debris and create protected breeding habitats. This hypothesis is being tested by a USUHS graduate student, Nicole Achee, as part of her dissertation with help and advice from Penny Masuoka (920). Nicole is currently sampling mosquito larvae along the Belize river in stretches of bamboo; forest and other land cover types. The SPOT images are being used to map the location of agricultural lands and forest along the Belize river in order to predict areas of bamboo growth. It is believed that bamboo growing along this river is not wide enough to map with the SPOT data, which has 20-meter pixels.

Remote Sensing and GIS Studies of Malaria in Thailand

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Don Roberts (USUHS)
Russ Coleman, US Army Thailand
Richard Kiang (NASA Goddard Code 902)

This new project uses remote sensing and GIS techniques to analyze field data collected by a larger, established project entitled "Mosquito Acquisition of Malaria (MaM): Role of host and vector factors as determinants of mosquito infection." Dr. Russell Coleman, US Army, Thailand, is the principal investigator for the larger project. The MAM project is a 3-4 year prospective study of approximately 480 individuals living in Ban Kong Mong Tha, Tambon Laivou, Kanchanaburi Province, Thailand. The study started in January 2000 and will end no-later-than December 2003. Monthly finger pricks of villagers are evaluated for malaria. Monthly collection of adult mosquitoes and larvae will allow seasonal and geographic distributions to be determined. Blood-engorged mosquitoes are collected throughout the village and the blood meal is subjected to DNA analysis. Using the DNA fingerprint obtained from each person in the village, the specific individuals who mosquitoes are feeding on will be determined.

The overall goal for the remote sensing/GIS studies is to use geographic information systems technology and remote sensing resources to research and define spatial relationships and the environmental, vector (mosquito) and host (human) roles of disease transmission and malaria incidence within the study village, Ban Kong Mong Tha. There are three main hypotheses:

1) The spatial distribution of malaria cases is clustered so that the majority of cases occur within a minority of houses.

2) The majority of mosquitoes stay within a short distance (<500m) of their last blood meal.

3) Environmental factors, such as proximity to water bodies and surrounding vegetation, determine the spatial distribution and density of mosquitoes and affect the distribution of malaria incidence within the village.

Hypothesis 1:
The spatial distribution of malaria cases within the village of Ban Kong Mong Tha is clustered so that the majority of cases occur within a minority of houses.

If malaria cases are spatially clustered, control programs can be planned to target the high malaria incidence houses to have a maximum impact with a minimum effort. Previous work in Belize found this spatial clustering of malaria cases, however, it is important to test this relationship, in other areas with other vectors. The Thailand site is an excellent study site not only because of the different vectors, but also because of the "closed" nature of the village (its inaccessibility gives few opportunities for movement in and out of the village).

Using data collected by the MaM Project, a GIS database is being constructed that contains house locations with attributes for each house including information such as the number of residents in the house, the number of malaria cases, and so forth. Maps will be created from the GIS database.

Hypothesis 2:
The majority of mosquitoes stay within a short distance (<500m) of their last blood meal.

If the clustering of malaria cases is shown to be true, the clustering may be caused by mosquitoes staying close to or returning to their original blood meal site. This hypothesis is important to test since there is currently a limited understanding of why malaria cases tend to be clustered.

The location of the mosquitoes' blood meals will be possible because the MaM Project will develop a DNA fingerprint for each individual in the study village. Blood-fed mosquitoes will be identified as to the source of their blood meal by testing the DNA in each bloodmeal. The distance from blood meal to capture location can be determined by creating a map with lines having endpoints representing the location of the blood meal and the capture location.

Hypothesis 3:
Environmental factors, such as proximity to water bodies and surrounding vegetation, determine the spatial distribution and density of mosquitoes and affect the distribution of malaria incidence within the village.

Clustering of cases within a small number of houses may be explained by environmental factors such as land use/land cover close to the house. A variety of types and scales of satellite data including 30-meter Landsat Enhanced Thematic Mapper + (ETM+) images, 4-meter Ikonos satellite images, and Radarsat images are being used for this project. Landsat and Radarsat provide an overview of the area and the location of major land cover classes within the area. Because of the scale of the project, and the need to know the land cover around individual houses, Ikonos imagery will be the most important remote sensing data set for this project and has been requested.

If the distance between blood meal and capture location for mosquitoes is low, buffer zones will be drawn around each house. The size of the buffer zone will be determined by the average distance from blood meal to capture. The buffer zones will be used to create a report on the amount of each land cover type within each buffer zone. Alternatively, if the distance between blood meal and capture location is high, the distance to the nearest mosquito-breeding habitat for each house will be determined.