USE OF A REMOTE SENSING-BASED GEOGRAPHIC INFORMATION SYSTEM IN THE CHARACTERIZING SPATIAL PATTERNS FOR *ANOPHELES MINIMUS* A AND C BREEDING HABITATS IN WESTERN THAILAND

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Abstract. A remote sensing (RS)-based Geographic Information System (GIS) was used to characterize the breeding habitats of *Anopheles minimus* species A and C in five different districts of Kanchanaburi Province in western Thailand. The GIS and RS were used to monitor the area for the presence and absence of *An. minimus* A and C in five major land areas, forest, agriculture, urban, water and bare land. The results show that *An. minimus* A survives both in dense canopy forest and in open fields where agriculture is dominant. A scatter plot of land-use/land-cover for *An. minimus,* considering proximities to the forest and proximities to agriculture, suggests that *An. minimus* A has a wider habitat preference, ranging from dense canopy forest to open agricultural fields. A scatter plot for *An. minimus* C, on the other hand, showed a narrow habitat preference. A scatter plot for proximities performed on separate populations of *An. minimus* species A, one in the north and the other in the south, showed that there was an association in the northern population with the forest and in the southern population with agricultural areas. There were no statistically significant differences in the scatter plot of proximities to urban areas and water bodies with the *An. minimus* A north, south, and *An. minimus* C. LANDSAT TM satellite data classification was used to identify larval habitats that produce *An. minimus* A and C and analyze proximities between land-use/land-cover classes and locations of larval habitats. *An. minimus* A has a wide habitat preference, from dense canopy forest to open agricultural fields, while *An. minimus* C has a narrow habitat preference.

INTRODUCTION

Thailand, one of the developing countries of Southeast Asia being confronting with endemic malaria, needs a reliable surveillance program to understand and manage its malaria problem. Understanding the spatial and temporal changes in anopheline mosquito abundance, quantification of the transmission potential of vector populations, and description of the distribution of host (human) populations are necessary prerequisites for predicting high-risk malaria areas. Modern tools, such as Remote Sensing (RS) and the Geographic Information System (GIS), are increasingly being used in studies of disease transmission and vector ecology.

The GIS is a powerful tool for studying and mapping the spatial relationships of objects. Such computer programs are designed to collect, store, manipulate, and display spatially referenced data (Liebhold *et al*, 1993). The spatial data managed by a GIS program may include items such as localities where mosquitoes have been collected, mosquito densities, distribution of mosquitoes relative to environmental parameters, such as climate or vegetation, human ar-

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tifacts, such as political boundaries or roads, boundaries of crop fields, and geologic information, such as topography and soil type. Similar data are typically grouped into individual layers or themes. The display of these layers can be turned on or off and modified to display various data. An important strength of the GIS is that it can simultaneously relate layers of data at the same points in space and can analyze and map out the results (Noonan, 2003).

RS is the science of collection of information about an object without physical contact. RS technology uses the visible, infrared red and microwave regions of solar radiation to collect information about the various objects on the earth's surface. The responses of the objects to the different regions of the electromagnetic spectrum are different, and are used to distinguish objects (Lillesand and Kiefer, 1987). RS technology has now reached a state where the application of satellite RS has been made operational in many countries in different disciplines. Existing satellite-borne sensors, for which data are available to the scientific research community, range from those in low altitude orbits with an infrequent repeat time to those in high altitude orbits which correspondingly low spatial resolutions but more repeat times. These contrasting categories of sensors provide information of potential use to epidemiology. These RS and GIS tools greatly enhance our abilities to analyze land use level relationships of vectors and diseases. Yet they can only be used successfully in combination with a thorough understanding of ecological and epidemiological processes of disease transmission.

Anopheles minimus sensu lato (subgenus *Cellia*, Myzomyia Series and Minimus Group) is a major malaria vector throughout Southeast Asia. In Thailand, its distribution is reduced on the peninsula and was not observed in the central plains, but remains abundant in forested hilly areas (Harrison, 1980). This species plays an important role in malaria transmission during the dry season, and during much of the rainy season when populations of *Anopheles dirus* are low along the Thai-Myanmar border (Sithiprasasna *et al*, 2003a). It is regarded as a species complex comprised of two species, with informal names of *An. minimus* A and C (Harbach, 1994). In Thailand, species A has been found predominantly, while species C is only seen in three provinces in western and northern Thailand (Kanchanaburi, Tak, and Chiang Mai) (Green *et al*, 1990; Sharpe *et al*, 1999, Kengluecha *et al,* 2005). Success of the approach to select the targeted interventions for vector control requires a good stratification of control areas in time and space, accurate information on vector biology and ecology, detailed information on vectorial capacity, and malaria transmission and epidemiology. Therefore, both correct species identification and real-time monitoring of the geographical distribution are needed to provide accurate information on elucidating the nature of the malaria vector species complex. In Thailand, the potential applications of RS/GIS technologies have been demonstrated in studying the epidemiology of dengue hemorrhagic fever (Sithiprasasna *et al*, 1997), to identify the breeding habitats of major malaria vectors and their distribution (Sithiprasasna *et al*, 2003b), to survey for dengue virus-infected *Aedes* mosquitoes (Sithiprasasna *et al*, 2004), and to predict malaria transmission risk (Sithiprasasna *et al*, 2005).

To predict areas with critical densities at the land use level is to: 1) develop an understanding of the vector ecology and define the environmental determinants of its presence and abundance (this step is based on field studies), 2) construct a database that characterizes the land use elements associated with the important aspects of vector biology and human habitation (RS and GIS are suitable tools for this step), 3) formulate and verify predictions of vector abundance. The malaria control program in Thailand requires an efficient monitoring and surveillance system. With the availability of affordable computers, information and telecommunication systems, a more effective monitoring and surveillance system for malaria in Thailand using GIS and RS should be developed. The aim of this study was to detect the environmental determinants of the presence and absence of *An. minimus* A and C in five different districts of Kanchanaburi Province. Properly used, GPS, RS and GIS should allow the location and quantification of malaria risk to be determined in a much more time effective and cost-effective way, and probably more accurately in many situations, than was previously possible.

Fig 1–Thematic map showing localities of breeding habitats of *An. minimus* A (blue dots), *An. minimus* C (red dots), both A and C (yellow dots) around the five districts, red flag represents location of each village.

MATERIALS AND METHODS

Study area

The study area was in a malaria-endemic area of western Thailand near the Myanmar border. It covers the 5 districts of Mueang, Sangkhla Buri, Si Sawat, Sai Yok, and Thong Pha Phum in Kanchanaburi Province. Most of the area is covered with forest (Ministry of Agriculture and Cooperatives, 2002) and with agricultural lands mainly located along rivers and highways (Kusabe and Higuche, 1992). Generally, the climate of the study area falls into 2 categories: wet, from May to October, and dry, from November to April. Heavy rain in May marks the start of cropping season.

Larvae collection

Anopheles larvae were collected from different sites in five districts of Kanchanaburi Province during February to June 2004. Larvae were collected from breeding habitats and reared to adults for species identification by morphological and molecular techniques. Geographical and ecological data were recorded for each of the collections. The coordinates for each larval habitat were recorded using a Global Positioning System unit (Garmin, model: III Plus, Olathe, KS, USA).

Satellite data

A LANDSAT Thematic Mapper (Path 130 and Row 50) acquired on 21 December 1989 with a spatial resolution of 30 x 30 m was acquired and analyzed for land-use/land-cover classifications using ENVI 3.4 (ENVI, 2000) image processing software. The LANDSAT data was radiometrically corrected and projected into UTM Zone 47, WGS 84 datum (Sarawut N, unpublished project report, 2004). A subset was made from the full scene of LANDSAT TM data covering Kanchanaburi Province, Thailand.

Land-use/land-cover classification

Supervised classification was performed to cluster pixels in the subset image data into land-use/land-cover classes. This was done by grouping homogenous pixels into regions of interest (ROI) that represent the desired land-use/land-cover classes in the output image. Topographic maps (1:50,000 scale) were used as references in defining ROIs, along with the description in (Kusabe and Higuche, 1992) of the main location of agricultural lands. Utmost attention was made in selecting ROIs that were homogeneous by exporting them to the n-D Visualizer function of ENVI 3.4 (ENVI, 2000) image processing software and correcting for overlaps between classes. After the ROIs were finalized, the maximum likelihood classification was performed on FCC bands 4, 3 and 2 to assign each pixel in the subset image data to the class that has the highest probability.

Five major land-uses were defined: forest, agriculture, urban, water, and bare land. The separability of agricultural fields with standing crops, forest, and water classes is good. From the false color composite (FCC) of LANDSAT TM, agricultural fields appear pink (or light red) and can be easily identified from forests, which appears dark red, and from blue to dark-color water classes. The bare land class may include harvested agricultural fields that have a similar spectral response as bare lands.

Since most of the area in Kanchanaburi Province is reserved forest and national park, primary land uses do not change drastically. Forest land covered 58% of the total land area in 1988 (Ministry of Agriculture and Cooperatives, 1990) and remains relatively intact at 54% in 1999; farm land changed from 22% in 1988 to 16% in 1999 (Ministry of Agriculture and Cooperatives, 2002). The rates of primary land use change in the study area could be safely assumed to be smaller than the provincial figures, considering that the 5 districts in the study area had mostly forest cover.

Fig 2–Locations of breeding habitats of *An. minimus* A (blue dots), *An. minimus* C (red dots), both A and C (yellow dots) from Global Positioning System overlaid on LANDSAT 5 Thematic Mapper (spatial resolution 30 x 30 m) satellite image. Yellow line represents district boundary.

The use of multi-temporal satellite images should allow more detailed classification of landuse/landcover, and is recommended for future studies.

Proximity analysis

One of the strengths of a geographic information system is its ability to analyze spatial arrangements of information in one or more data layers. The ability to identify items in proximity to each other is one of the classic functions of a GIS (Stan and Estes, 1990). Proximity analysis allows determining which map features are located near or within the neighborhood of target map features, and is widely used for environmental planning and impact assessment (Landis, 1993).

Proximity analysis was made on all major land cover classes except bare land. Proximity was calculated by summing up 1/(R*R) for each

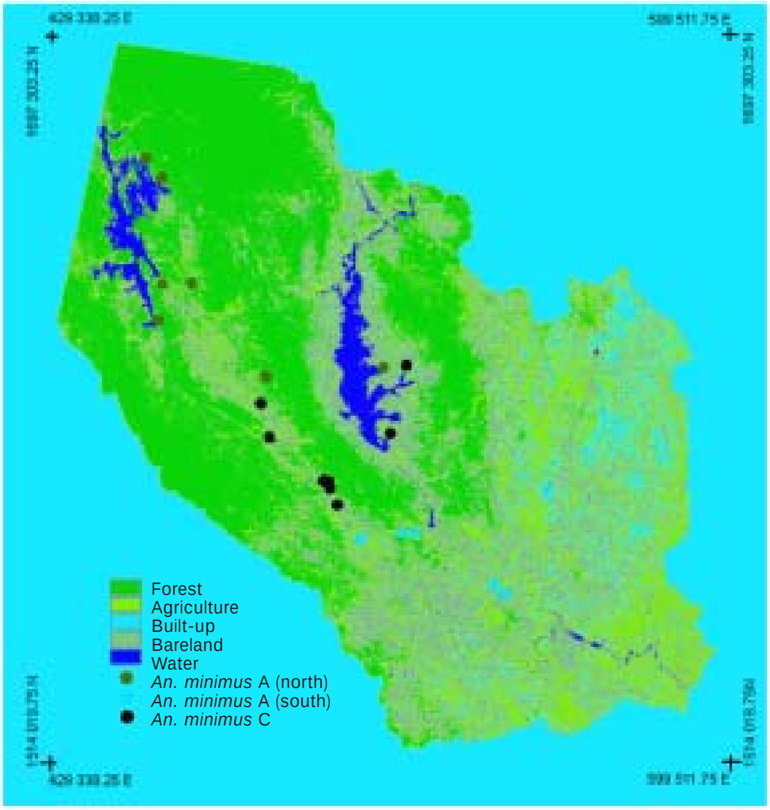


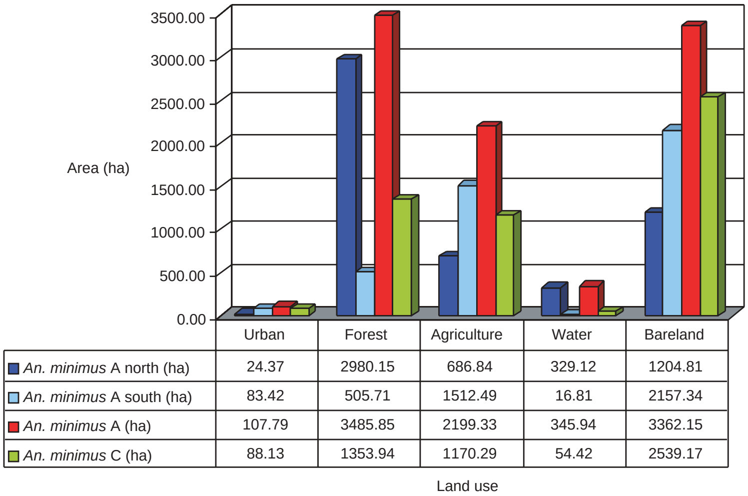
Fig 3–Classified LANDSAT image showing land-use/land-cover of the study area.

concerned land class, where R is the distance from the target pixel (center of the window) to other pixels in the window. Proximity is commonly measured in units of length but can also be measured in other units (Arnoff, 1993). In this study, proximity was normalized in the window, and thus was unitless. If all pixels in the window were paddy, the proximity becames 1. A window size of 1.5 km by 1.5 km was used based on the estimated flight range of *An. minimus*.

RESULTS

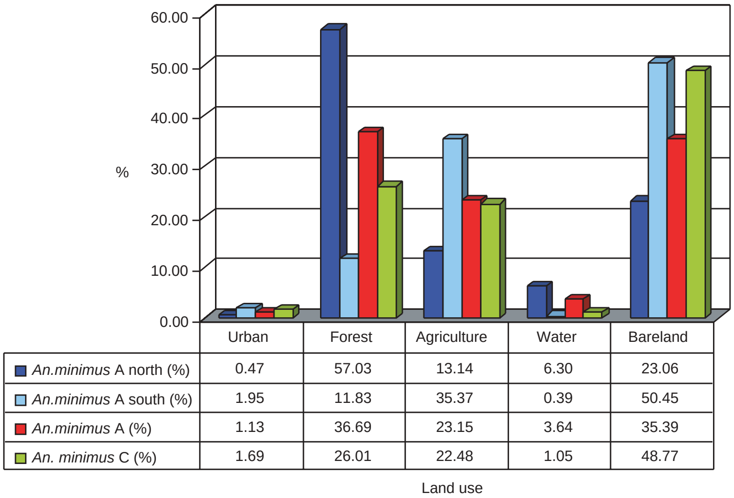
Figs 1 and 2 depict the localities of the breeding habitats from the GPS units for *An. minimus* A in blue dots, *An. minimus* C in red dots, and both A and C in yellow dots around the five districts (Mueang, Sangkhla Buri, Si Sawat, Sai Yok, and Thong Pha Phum districts, Kanchanaburi Province). Red flags in Fig 1 represent the location of each village. A LANDSAT 5 Thematic Mapper (spatial resolution 30 x 30 m) satellite image dated 21 December 1989 was used as the base map for Fig 2 as a yellow line representing a district boundary. As shown in Fig 2, the northern districts in Kanchanaburi Province are mostly forested areas while the middle and southern areas are agricultural areas and bare land. Fig 3 depicts the land-use/land-cover classification of the study area. The depicted area displays forest, agriculture, urban, bare land, and water (depicted by green, yellow, white, gray, and blue, respectively).

As shown in Fig 4A, the total land-use area within the 1.5 km buffer breeding habitat for *An. minimus* A was higher than for *An. minimus* C. Since the habitat of *An. minimus* C is confined to the middle region, we asked whether the area of land use for *An. minimus* A in the northern area is different from that of the southern area. As shown in the same figure, forest land use was predominantly occupied by *An. minimus* A in the north, while both species C and A in the south occupied the agricultural areas and bare land. The total areas corresponding to land-use, as shown in Fig 4A, depend on the number of samples where the buffers were generated. Fig 4B shows the proportion of land-use for the total buffer area in each series and the proportion of land-use for *An. minimus* A in the north, *An. minumus* A in the south, and *An. minimus* C. The results show that *An. minimus* A thrives both in dense canopy forest and in open fields where agriculture is dominant. Scatter plots of total forest and agricultural areas for each buffer case clearly illustrate the results. Fig 5A shows that buffer cases of *An. minimus* A in the north had the highest forest area per case, fol-



	Urban	Forest	Agriculture	Water	Bareland
🟦 *An. minimus* A north (ha)	24.37	2980.15	686.84	329.12	1204.81
🟦 *An. minimus* A south (ha)	83.42	505.71	1512.49	16.81	2157.34
🟥 *An. minimus* A (ha)	107.79	3485.85	2199.33	345.94	3362.15
🟩 *An. minimus* C (ha)	88.13	1353.94	1170.29	54.42	2539.17

Fig 4A–Land-use within 1.5 Km buffer of *An. minimus* locations.



	Urban	Forest	Agriculture	Water	Bareland
🟦 *An.minimus* A north (%)	0.47	57.03	13.14	6.30	23.06
🟦 *An.minimus* A south (%)	1.95	11.83	35.37	0.39	50.45
🟥 *An.minimus* A (%)	1.13	36.69	23.15	3.64	35.39
🟩 *An. minimus* C (%)	1.69	26.01	22.48	1.05	48.77

Fig 4B–Proportion of each land-use to the total buffer area of *An. minimus* locations.

lowed by *An*. *minimus* C, then by *An. minimus* A in the south. The scatter plot in Fig 5B shows that the total agriculture area for each buffer case was highest for *An. minimus* A in the south, followed by *An. minimus* C, then by *An. minimus* A in the north.

An. minimus A in the north had the closest proximity to forest, followed by *An*. *minimus* C, then *An. minimus* A in the south (Fig 6A). Based on earlier results showing an association of *An. minimus* A to forest land use, *An. minimus* A and *An. minimus* C were compared (without segmenting *An. minimus* A to the north and south) by one-sided statistical test of their mean proximity to the forest. The results show a significant difference in their means at 5% significance level, meaning *An. minimus* A had a closer proximity (bigger proximity mean) to forest land use than *An. minimus* C. The results show a highly significant difference, at a 5% significance level, when mean proximities to the forest for *An. minimus* A in the north are compared to *An. minimus* C. Fig 6B shows the proximity to agriculture for all the *An. minimus* species. The proximity means for *An*. *minimus* A and *An. minimus* C (to agriculture) were not significantly different. We found the same results when testing mean proximities between *An. minimus* A south and *An. minimus* C. However, mean proximities to agriculture were significantly different between *An. minimus* A north and *An. minimus* C. Fig 7 shows proximities to forest and agriculture. The figure shows clearly that *An. minimus* A has a wider habitat, from dense canopy forest in the north to open agricultural fields in the south. *An. minimus* C, on the other hand, has narrow habitat preference.

DISCUSSION

RS-based GIS was used to characterize the breeding habitats of *Anopheles minimus* species A and C in five different districts of Kanchanaburi Province, western Thailand. LANDSAT satellite data classification was used to identify larval habitats that produce *An.*

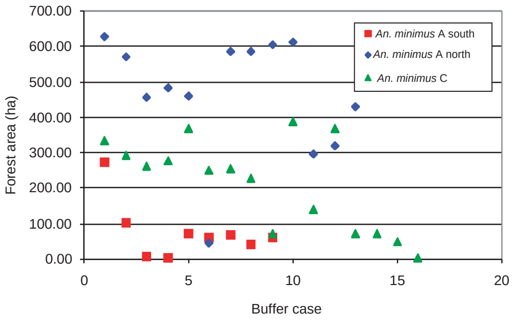


Fig 5A–Scatter plot of the total forest area in each buffer case.

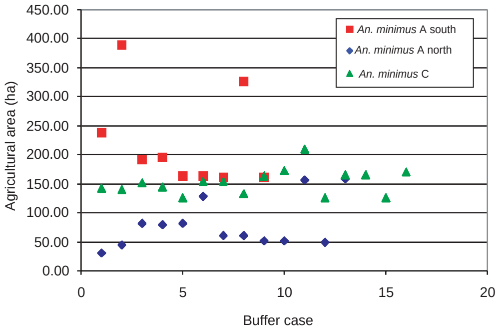


Fig 5B–Scatter plot of the total agriculture area in each buffer case.

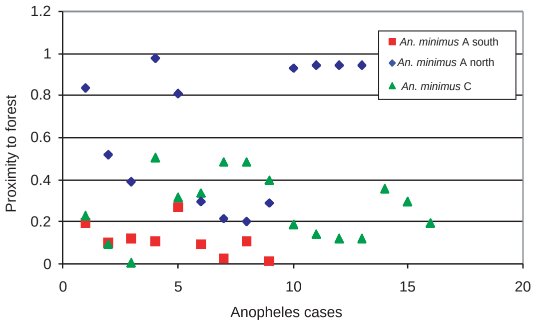


Fig 6A–Scatter plot of proximity to forest land-use for all *An. minimus*.

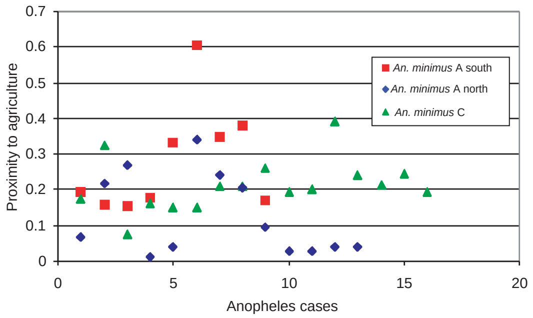


Fig 6B–Scatter plot of proximity to agriculture land-use for all *An. minimus*.

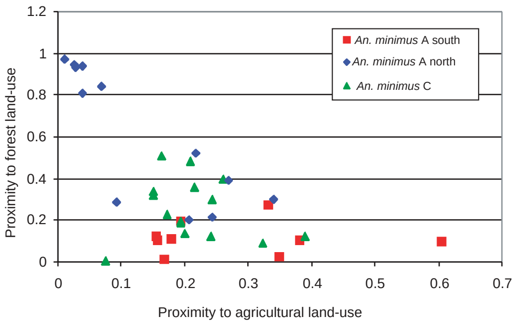


Fig 7–Scatter plot of proximities to forest and proximities to agriculture. The figure shows clearly that *An. minimus* A has a wider habitat adaptation, from dense canopy forest (in the North) to open agricultural fields (in the South). *An. minimus* C, on the other hand, has a narrow habitat preference.

minimus A and C. Proximities between land-use/land-cover classes and location of larval habitats were analyzed. *An. minimus* A has a wide habitat preference, from dense canopy forest to open agricultural fields, while *An. minimus* C has a narrow habitat preference. These systems are valuable tools, allowing for information regarding malaria transmission and malaria risk to be processed and used to guide the management of malaria control campaigns.

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