The Use of Remote Sensing for Predictive Modeling of Schistosomiasis in China

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Abstract

The development of predictive models of the spatial distribution of schistosomiasis are hampered by the existence of different regional subspecies of the Oncomelania hupensis *snail that serve as intermediate hosts for the disease in China. The habitats associated with these different subspecies vary considerably, with mountainous habitats in the west and floodplain habitats in the east. Despite these challenges, continuing environmental change resulting from the construction of the Three Gorges Dam and global warming that threaten to increase snail habitat, as well as limited public health resources, require the ability to accurately map and prioritize areas at risk for schistosomiasis. This paper describes a series of ongoing studies that rely on remotely sensed data to predict schistosomiasis risk in two regions of China. The first study is a classification of Landsat TM imagery to identify snail habitats in mountainous regions of Sichuan Province. The accuracy of this classification was assessed in an independent field study, which revealed that seasonal flooding may have contributed to misclassification, and that the incorporation of soil maps may greatly improve classification accuracy. A second study presents the use of Landsat TM and water level data to understand seasonal differences in* Oncomelania hupensis *habitat in the lower Yangtze River region.*

Introduction

Schistosomiasis is a water-borne parasitic disease that affects 200 million people and poses a threat to 600 million in more than 76 countries (WHO Expert Committee on the Control of Schistosomiasis, 1993). Within China it is estimated that approximately 865,000 people are infected and 40 million are at risk (Chen and Feng, 1999). The disease is caused by infection by parasitic worms of the species *Schistosoma japonica*, whose lifecycle depends upon the availability of an intermediate snail host of the species *Oncomelania hupensis* (Webbe *et al.*, 1993).

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Schistosomiasis is a disease whose distribution is particularly sensitive to environmental change, most clearly environmental change of human origin. There are two events looming which promise major environmental changes: the construction of the Three Gorges Dam and the increasing probability of global warming. The changes caused by these events promise to have a substantial impact on the distribution and extent of schistosomiasis japonica in China. Hotez *et al.* (1997) have written on the impact of the dam, speculating that the effect will generally be to increase both *Oncomelania* snail habitat and human disease transmission. In this regard, it is not generally understood, even in China, that there are at least three genetically distinct subspecies of *Oncomelania* in China living in considerably different ecological settings. The genetic and biogeographic differentiation of these taxa has only recently been clarified through Shanghai-based Tropical Medicine Research Center (TMRC) research (Davis *et al.*, 1995; Spolsky *et al.*, 1996; Davis *et al.*, 1998). The two major subspecies are *O. h. robertsoni*, which are found above the Three Gorges of the Yangtze River in Yunnan and Sichuan Provinces, and *O. h. hupensis*, occurring below the Three Gorges in the Yangtze River basin (Figure 1).

Until now, the Three Gorges of the Yangtze have been an effective barrier separating the two subspecies and their schistosomes. Snails cannot survive the strong currents of the gorges. With the advent of the Three Gorges Dam, a number of changes will occur that require in-depth GIS/RS ecological monitoring in the immediate future:

- Canals on each side of the dam will permit passive movement of snails in both directions; *O. h. hupensis* will be able to invade suitable habitats above the dam at the margins of the lake where marshlands will be created;
- There will be a potential for mixing genetic stocks of schistosomes and snails; and
- While the river below the dam will have a somewhat greater depth than at present, there will be a dampening of the annual Yangtze flood.

We predict that one result will be that a substantial land mass will be above water all year round in Poyang Lake, making for excellent snail habitat year round, and with resulting changes in snail life tables and infection patterns.

The impact of global warming on the geographical distribution of schistosomiasis is more speculative. The work of Martens (1997) supports the possibility of the spread of the disease at higher altitudes in currently endemic areas such as the eastern highlands of Africa and the mountainous regions of

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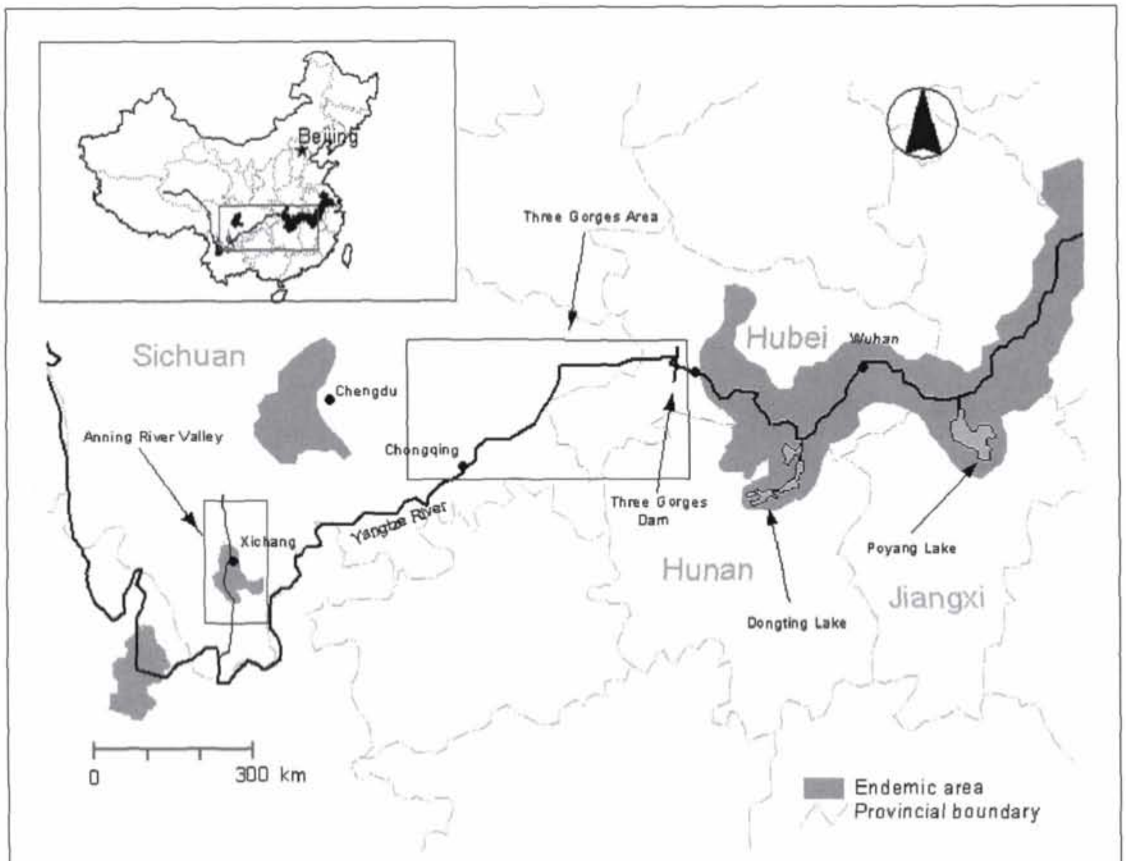

Figure 1. Map of the Three Gorges Dam region and adjacent endemic schistosomiasis areas including the Anning River Valley and Poyang Lake.

western China based on studies of the global warming potential using Intergovernmental Panel on Climate Change (IPCC) scenarios regarding greenhouse gas emissions and both the Global Climate Change and General Circulation models. Indeed, there is some preliminary evidence in Hunan that colder mountainous areas at the edge of *Oncomelania* habitat in that province, e.g., Tao Yuan and Juzi Zhoutou, where disease transmission did not previously occur, became sites of transmission in July 1997. Experience in the mountainous regions of Sichuan suggests that disease transmission does not occur when mean annual water temperatures fall below 15°C. Hence, it can be forecast that global warming would increase the altitude range where the disease is endemic.

There is little question that the potential effects on schistosomiasis transmission of these large-scale environmental changes makes it essential to understand the ecological circumstances conducive to snail habitat and disease transmission. Remote sensing and GIS technology promise to aid the identification of new areas of potential snail habitat and sites with high potential for disease transmission, based on image analysis and specification of land-cover features associated with agriculture and human habitation. Brooker *et al.* (2000) present environmental factors associated with schistosomiasis transmission that are amenable to remote sensing. These factors include temperature, soil moisture, rainfall, water velocity, and altitude. Brooker *et al.* (2000) also describe previous remote sensing studies of schistosomiasis, such as for the Philippines (Cross *et al.*, 1984; Cross *et al.*, 1996) and for the Nile delta in Egypt (Malone *et al.*, 1994), and additionally present a new case study for Tanzania. However, the environmental conditions for schistosomiasis transmission within China are quite different than those summarized by Brooker *et al.*, (2000) whose focus is on African schistosomiasis and related snail species. The main difference is due to *Oncomelania hupensis*, the intermediate host in China, being an amphibious snail, rather than a totally aquatic snail, which is the case in Africa. Moreover, even within China, there are substantial regional differences in snail habitats and transmission that must be recognized and understood as they impact GIS and remote sensing studies. Here, we extend our previous work (Spear *et al.*, 1998) by presenting a general summary of the ecology of *Oncomelania hupensis*, describe how this ecology differs in two regions of China, one above the Three Gorges Dam in the mountainous regions of Sichuan Province, and the other below the dam in Poyang Lake in the lower Yangtze River region, and present our remote sensing work in both regions.

The *Oncomelania hupensis* Snail of China

Much of the data on *Oncomelania hupensis* ecology exists only in the Chinese literature, with key studies published in the 1950s and summarized by Guo (1990). A key difference between the *Bulinus* and *Biomphalaria* species of snails that transmit the schistosome parasite in Africa and the Chinese *Oncomelania hupensis* is that the latter is amphibious, rather than purely aquatic. Early in its life, *Oncomelania hupensis* must live in water to survive. However, once adults, the snails can no longer live completely in water. Instead, they prefer to live in soil just above the water line. In this environment, appropriate temperature and moisture are critical for the snails. Field studies have shown that the optimum temperature for snail reproduction is from 20 to 25°C (Su, 1986). However, snails are alive, but nearly inactive, at temperatures as low as 2 to 4°C.

Laboratory experiments assessed snail survival between −14 and 42°C. In a dry cold environment, even at −3°C, snails were found to survive 31 days. If the environment becomes too hot or too dry, the snails will protect themselves by sealing themselves into their shells. However, at high temperatures of 29 to 30°C and 38 to 42°C, even with access to water, snails died in 48 and 12 hours, respectively. Snail activity increases with soil moisture. For 12.25 percent, 20 percent, and 30 percent soil moisture, corresponding snail activity was found to be 0.28 percent, 21 percent, and 51.6 percent, respectively. Snails can survive dry spells longer if temperature is low. Hence, dry spells in summertime temperatures are most detrimental to snails.

Oncomelania hupensis prefers heavily vegetated soils. Snails often cling to the base of grasses, which provide a perfect environmental buffer, protecting them from direct sunlight, rain, and extreme fluctuations in temperature and moisture. Their preference for vegetated soil was confirmed by a field study that found a positive correlation between grass density and snail density, with high grass areas having 65 percent snail density, medium grass areas having 38 percent snail density, and low grass areas having 0 percent snail density (Guo, 1990). The composition of the soil is also an important factor for snails. Snails prefer soils rich in phosphorus, calcium, nitrogen, and organic matter. The presence of organic matter is particularly important for snail nutrition. In Sichuan Province, several geographic land covers are suitable for snail habitat; however, snails are most abundant in sedimented vegetated land unaffected by flooding (Guo, 1990). This land has the highest levels of nitrogen, phosphorus, and organic matter. Areas at the margin of flooding, with lower levels of soil nutrients, were found to be less suitable for snails.

Altitude is also an important consideration in schistosomiasis transmission. In the Daliang Mountain region, transmission occurs between 1000 and 2230 m above sea level (Gu, 1990). In the mountains of Yunnan Province, schistosomiasis endemic areas lie between 1350 and 2450 m above sea level (Tan *et al.*, 1990). However, the amount of transmission varies within these ranges of elevation. In Yunnan, the prevalence of human cases was highest around 1800 m.

Mountainous Regions of Sichuan Province

The *Oncomelania hupensis robertsoni* subspecies of snail that lives upstream of the Dam in Sichuan Province is described by Davis *et al.* (1999). Life tables indicate that snails can live two or more years in the mountainous areas unaffected by the annual floods of the Yangtze River. These snails are adapted to a colder climate than those of the Yangtze basin, and live in terraces, nooks, and crannies where there is an appropriate climate and mixture of soils, vegetation, and organic matter on which to feed. They are often distributed along irrigation ditches that feed rice fields and terraces.

The interaction between snail habitat and human activity determines the magnitude of disease transmission. Humans are organized into residential groups, which serve as both political and social-cultural boundaries. The living and working style of people in a residential group are usually very similar, and the fields that they farm are usually adjacent to their housing areas. In general, the agriculture typical of the mountainous river valleys does not rely heavily on animal husbandry; hence, animal populations contribute very little to the persistence of the disease. However, an important factor to sustaining the parasite in this area is that fertilization practices make extensive use of human and animal excrement which is moved from residential pit latrines to field storage pits without treatment and with minimal holding times. Parasitic eggs are spread into the environment through fertilization, resulting in snail infection. Infected snails release the cercarial form of the parasite that infects both adults who work the fields and perform household washing in ditches and children who play in the water.

Landsat TM Classification of Snail Habitats

In order for schistosomiasis to persist, suitable environmental conditions must exist for the snail vector to establish itself and complete the lifecycle of the parasite. The goal of our Sichuan study was to use Landsat TM to identify habitats suitable for *O. h. robertsoni*, and distinguish these habitats from non-habitats that do not support snails in the mountainous regions of Sichuan. It was hypothesized that at a macroscopic level visible from TM imagery there may exist environmental factors useful in the determination of habitats suitable for snails. These environmental factors may include vegetation, crop type, soil type, moisture, and temperature. All of these factors vary from region to region and may affect the suitability of an area to support snails. However, it is also important to understand that these ecological differences might be quite slight and, in some cases, not observable using remote sensing, such as the use of molluscicide.

Our study was carried out for the Anning River Valley in the vicinity of Xichang, which is a highly endemic area for schistosomiasis. The Anning River Valley is a high mountain valley at an elevation of about 1500 m and is dense with irrigated farming of rice, corn, wheat, and a variety of vegetables and some export crops. Two Landsat TM scenes (one Spring 07 April 1994, and one Fall 16 October 1994) were obtained for the region to capture both agricultural seasons. In 1994, the Xichang County Anti-endemic Station (XCAS) conducted a large-scale snail monitoring effort. These monitoring sites were revisited in the summer of 1997 and precisely located using differential GPS. This resulted in a total of 103 sites (55 classified as habitat where there existed snails and 48 as non-habitat where there were no snails found). Each site corresponded to a 3- by 3-pixel area of the Landsat TM images, where each pixel was allowed to represent an individual data point in the analyses.

In a typical supervised remote sensing classification, it is possible to use the spectral reflectance associated with snail habitat sites as one signature, and non-habitat sites as another signature. Each pixel in the image can subsequently be compared against these two signatures, and classified as snail habitat, non-habitat, or neither. However, an analysis of the spectral properties of snail habitat sites revealed considerable variability, suggesting that multiple habitats probably exist. There was also considerable variability among non-habitat sites. Moreover, when consider as a whole, snail habitat and non-habitat signatures overlapped. To tease out the heterogeneity within snail habitat and non-habitat sites, a multivariate cluster analysis, ISODATA clustering (Tou and Gonzalez, 1977), was performed. The spectral data were found to naturally break into ten spectral signatures: five for snail habitat sites, and five for non-habitat sites. As far as ecological interpretation of these signatures is concerned, all ten signatures represent some form of agricultural landscape within the valley, because they were based on field data collected from *potential* snail habitat. In other words, these sites, both habitat and non-habitat, would not have been surveyed if it was not thought that snails could exist in these environments. As snails require year-round moisture and shade, non-habitat signatures probably correspond to dry crop farming, bare fields, or drained ditches in one of the two seasons. For example, many non-habitat sites close to the Anning River bed were surveyed, where crops such as corn are grown, but in rather rocky, pebble-like soil, suitable for corn, but not ideal for snails. Conversely, habitat signatures correspond to year-round vegetated fields, with different proportions of wet field type crops, such as rice, vegetables, tobacco, flowers, and lush ditch vegetation. The five snail habitat signatures and five non-habitat signatures were subsequently used to perform a supervised classification using maximum-likelihood classification (Duda and Hart, 1973; Swain and Davis, 1978; Schowengerdt, 1983; Foody *et al.*, 1992).

The resulting classification (Plate 1) was promising in that areas generally known to be snail habitat were correctly identified, and areas such as the surrounding forested mountains, lake, and urban areas—areas that were not surveyed as potential habitat, and which do not have snails—were excluded. Moreover, the classification appeared to be able to discriminate well between subtle differences in snail habitat and non-habitat. Particularly impressive was the ability to identify irrigated agricultural areas along the riverbed—that tend to have rockier, sandier soils, which do not support snails—as non-snail habitat. The original 103 habitat and non-habitat training sites were classified with 89 percent accuracy. The classification accuracy matrix is presented in Table 1. Below, the results of a separate field validation of the classification are presented.

A shortcoming of the classification map was that it only presented snail habitat and non-habitat areas without any indication of the certainty with which an area was classified. A modification of the maximum-likelihood classification was created to produce an estimate of the certainty with which a pixel is *Oncomelania* habitat. A ranking statistic, R, was computed based on the maximum-likelihood probabilities assigned to each of the ten classes, where a zero ranking represented a null classification and non-zero rankings from 1 to 255 were assigned based on a weighted-average of the probabilities assigned to *Oncomelania* habitat classes versus non-habitat classes (Equation 1), where $P(C_i \mid x)$ represents the probability that a pixel with a TM signature x belongs to the ith spectral signature: i.e.,

$$R = 255\,\{P(C_1 \mid x) + P(C_2 \mid x) + P(C_3 \mid x) + P(C_4 \mid x) + P(C_5 \mid x)\} + \{P(C_6 \mid x) + P(C_7 \mid x) + P(C_8 \mid x) + P(C_9 \mid x) + P(C_{10} \mid x)\}. \quad (1)$$

The result of this modification (Plate 2) is presented as a gradient of colors that represents the certainty with which a pixel is *Oncomelania* habitat. Such a presentation also has implications for practical public health resource allocation problems, because one can envision the possibility of assigning different field research priorities and/or disease and snail control strategies to different levels of the R-statistic.

Validation Study of Landsat TM Classification

Given the increase from two to ten spectral signatures, and the number of TM bands from using images from two seasons with our methodology, there was valid concern that a classification with so many variables might over-fit the limited training data, resulting in overestimated accuracy. In light of this concern, in 1998 we revisited the Anning River Valley with the purposes of validating the previous classification and developing a better understanding of the ecology of the Sichuan *Oncomelania*. A stratified random sampling procedure was used to select 111

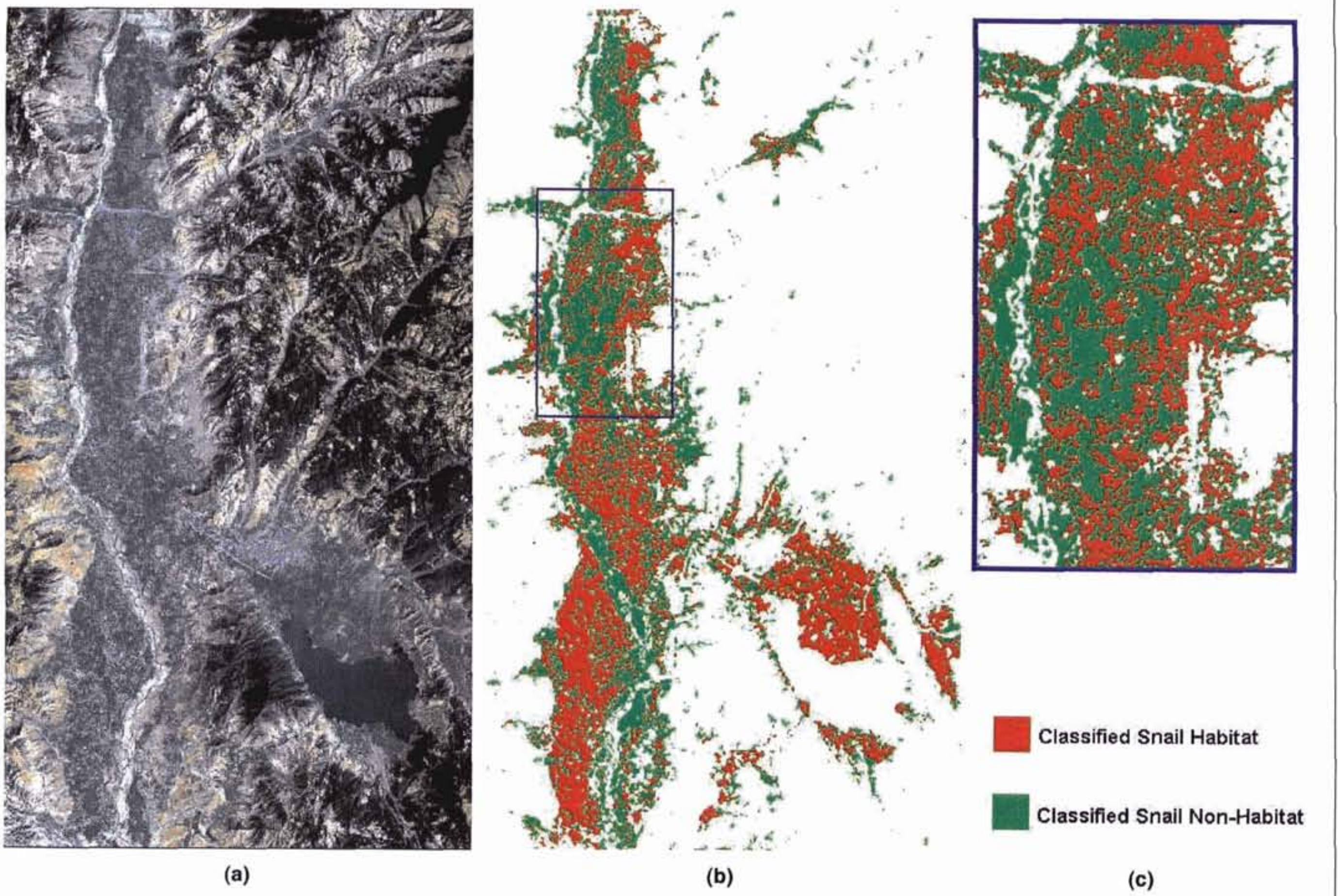

Plate 1. Three panels showing (from left) (a) Landsat TM of Anning River valley, (b) classification of habitat using Isodata and maximum-likelihood algorithms, and (c) enlargement of valley floor showing mixed habitat.

Table 1. Classification Accuracy Matrices. Each Field Survey Site Corresponds to a 3- by 3-Pixel Area, Resulting in 55 Snail Habitat Sites = 495 Snail Habitat Pixels, and 48 Non-Habitat Sites = 432 Non-Habitat Pixels

	Total # Pixels	% Unclassified Pixels	% Classified within Snail habitat Signatures	% Classified within Non-habitat Signatures
48 Non-habitat Sites	432	4.2	12.6	83
55 Snail habitat Sites	495	3.6	87.1	9.2

	Total # Pixels	% Uncl. Pixels	Snail habitat Signatures					Non-habitat Signatures				
			% C_1	% C_2	% C_3	% C_4	% C_5	% C_6	% C_7	% C_8	% C_9	% C_{10}
48 Non-habitat Sites	432	4.2	6.9	3.7	0.2	1.6	0.2	28.9	9.0	18.3	11.8	15.0
55 Snail habitat Sites	495	3.6	31.3	23.6	8.5	17.6	6.1	4.8	0.0	4.0	0.0	0.4

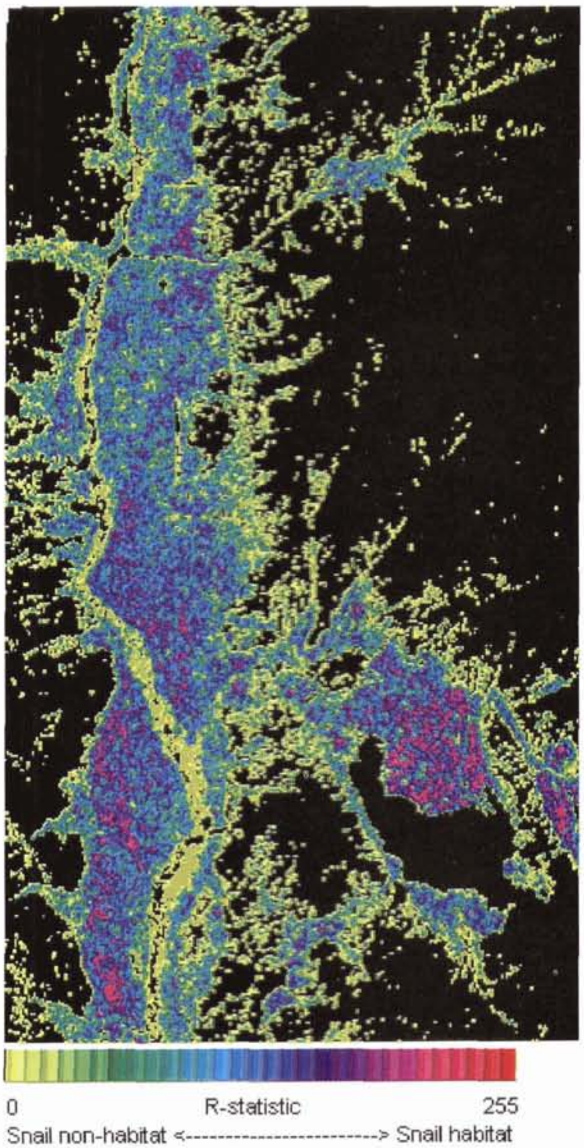

Plate 2. Snail habitat priority ranking for the 1994 Landsat TM classification of the Anning River valley. Colors range from black (not potential snail habitat), and yellow for the lowest surveillance priority, to red for the highest surveillance priority.

new locations in the valley. Each location was navigated to using GPS. At each location a snail survey was performed to determine snail habitat status; however, instead of just categorizing each site as snail positive or negative, a third class was considered, which we termed marginal habitat sites. Marginal habitat was defined as sites where no *Oncomelania* were found, but ecologists felt that *Oncomelania* could exist. Their judgement was based on the observation of the ditch construction, water flow, vegetation, and surrounding environment. Of the 111 sites, 35 were snail sites, 47 were non-snail sites, and 29 were marginal habitat sites. In addition to determining snail status, soil samples were taken for laboratory analysis of moisture, texture, pH, conductivity, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, and extractable phosphorus, potassium, sulfur, copper, iron, manganese, zinc, calcium, magnesium, and chlorides.

The previous 1994 classification could not be validated against the new 1998 field data due to development in the Anning River Valley over the course of four years. Instead, two new Landsat TM images were obtained for 1998 (17 March and 28 November) and were classified using the same spectral signatures developed in the 1994 classification. Of the 111 test sites, 104 were assigned a non-zero *R*-statistic by the classification, suggesting that the classification was quite good at identifying the potential habitat of irrigated agricultural land. However, the classification did not perform as well in distinguishing between snail positive and negative sites. Excluding the seven unclassified sites and 29 marginal habitat sites, an overall accuracy of 60 percent was determined by computing the percentage of validation sites where snail status was correctly identified by remote sensing (sensitivity of 59.4 percent and specificity of 60.5 percent). This level of accuracy was disappointing in light of the initial overall accuracy of 89 percent computed from the training set pixels, warranting an exploration of factors that could explain the misclassification.

One factor that may have contributed to misclassification was severe flooding along regions of the Yangtze and Anning rivers in late June and July 1998. During this time, southern regions of the Anning River valley were covered with water, substantially changing the environment for snails. Recall that adult snails cannot live underwater, and that nutrient-depleted soils from flooding are not ideal habitats. Because snail statuses for the validation sites were determined in the summer before the flooding, many of the yes-snail sites in the south that were covered by the flood did not have the reflectance signature of snail sites when the fall image was acquired. Thus, the classification, based in part on fall imagery that captured the ecological changes associated with the flooding, classified the sites as non-snail. Of the 13 snail sites that were misclassified, nine were in flood regions according to the Xichang Department of Civil Administration. If we consider that the remote sensing classification was probably correct in identifying these flooded sites as non-habitat sites, the overall accuracy of the classification is increased to 72 percent.

A second factor that may have contributed to misclassification was soil properties that have the potential to exclude *Oncomelania* from what otherwise would appear to be suitable habitat. It was hypothesized that misclassification of the non-snail sites and marginal habitat sites was related to soil factors that were neither discernable by the remote sensing classification, nor available to the field ecologist. A classification of snail sites versus non-snail sites (excluding marginal sites) based on soil properties was created using Classification and Regression Trees (CART) (Breiman, 1984; Steinberg and Colla, 1997). Multivariate discriminant analysis is commonly used in remote sensing studies to classify such things as high versus low disease prevalence, as used by Cross *et al.* (1984; 1996) in their study of schistosomiasis. CART is a multivariate discriminant analysis. However, CART is non-parametric, and typically outperforms general linear methods. Through brute-force computation, CART can determine the most important soil properties that can be used to distinguish between snail and non-snail sites, and reveals potentially important interactions between soil properties in the form of a decision tree. The CART analysis resulted in a six-variable decision tree using magnesium, sulfur, phosphorus, silt, chloride, and potassium that discriminated between snail and non-snail sites with an 85.5 percent cross-validated accuracy (sensitivity of 74.3 percent and specificity of 93.8 percent) (Figure 2). The tree was particularly useful in describing the soil characteristics that were unfavorable for snails. For example, of the 17 non-snail sites that were misclassified by the remote sensing classification, 16 (94.1 percent) could be explained by tracing their soil properties down the CART tree, with 11 sites (64.7 percent) falling within node T1, four sites (23.5 percent) falling within T6, and one site (5.9 percent) falling within T3.

The large number of sites that were classified into node T1 suggests that the combined lack of critical levels of magnesium, sulfur, phosphorus, and silt may prevent the establishment of *Oncomelania*. However, the importance of these particular soil properties should not be emphasized too strongly, because many of the properties of soil are correlated. Because of these correlations, this particular CART tree, although accurate and able to explain why sites cannot support snails, may not represent all the underlying factors that contribute to exclude *Oncomelania*. Silt abundance is, however, an important component within the *Oncomelania* lifecycle, because silt is used to coat their eggs. Magnesium, sulfur, and phosphorus may relate to the abundance of diatoms in the soil, upon which the snails feed.

The marginal habitat sites were considered both from the perspective of remote sensing as well as the CART soil classification. The majority (60 percent) of these sites were classified by the remote sensing classification as snail sites, agreeing with the opinion of the field ecologists. Moreover, the distribution of the priority rankings for the marginal habitat sites was the same as that for the snail sites, suggesting that these sites do indeed look like snail sites from the remote sensing standpoint, as well as to the ecologist in the field. However, once soil factors for these sites are considered, it is clear why many are actually non-snail sites. Because data from the marginal habitat sites were excluded during the creation of the soil CART tree, the tree can be used to independently test the marginal habitat sites. The soil data from the marginal habitat sites were classified by the tree, resulting in 72.4 percent of the sites being correctly identified as non-snail sites.

Although the soil analysis seems quite useful in discriminating between snail habitat and non-habitat, our intention is not necessarily to advocate the routine collection and analysis of soil samples, because even the analysis of just the six relevant soil properties is logistically more difficult than directly performing snail surveys for a village. However, it is our intention to point out the importance of soil composition, and hope that our soil findings can be generalized such that they can be incorporated into GIS and remote sensing studies. For example, we look to further studies to find potential correlation between soil properties and soil types, for which soil maps may be available for some regions of China. Correlation may also exist between soil properties and certain crops and landscapes, which when better understood will lead to improved remote sensing classifications of snail habitat.

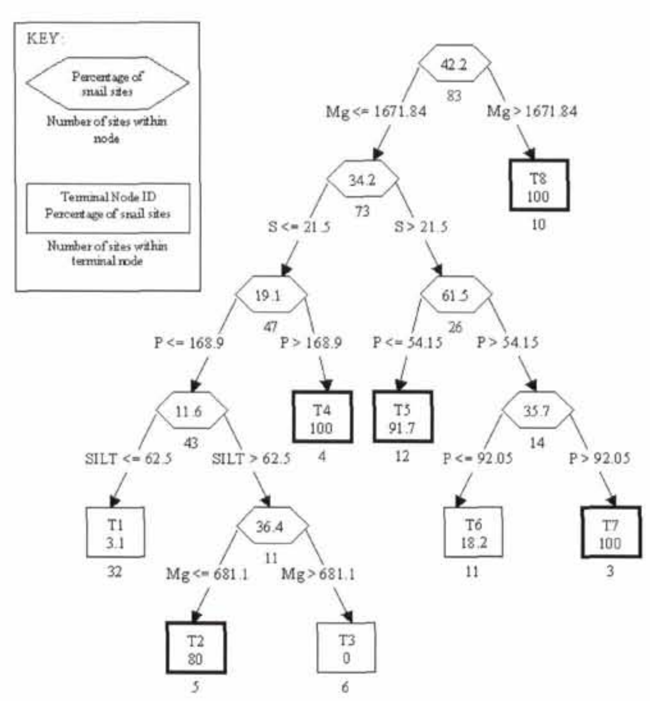

Figure 2. Decision tree produced by the CART procedure for the six ecological variables. At each node, the number below the hexagon is the number of sites represented by the node. The number within the hexagon is the percentage of those sites that are snail sites. The tree is read from the topmost node down, where inequality relationships are evaluated at each node and lead to subsequent children nodes in the tree. A site is classified as snail habitat or non-habitat by moving down the tree based on its soil properties, reaching a terminal node, where a terminal node with a dark frame represents a classification of snail habitat, and a thin frame represents a classification of non-habitat. Units shown are lbs/acre for Magnesium and Phosphorus, ppm for Sulfer, and percent for Silt. Of particular note is the T1 terminal node, which represents a large number of sites that may not support *Oncomelania hupensis robertsoni*.

Lower Yangtze River - Poyang Lake Region

Snail ecologies and schistosomiasis transmission in the lower Yangtze River region is quite different from the Sichuan mountainous region (1999). Poyang Lake of Jiangxi Province is the largest fresh water lake in China, more precisely a riverbed of the Gan Jiang River that opens to the Yangtze River with a very narrow mouth. During the dry season only some sections of this riverbed have water. However, during the wet season when the Yangtze floods, the riverbed fills with water, held back by a series of dikes that contain and constrain the lake. It is during this season, typically from May to October, that Poyang Lake reaches some 140 km long and 40 km wide at the widest. Only fishermen can venture out on this vast lake. There are no snails or disease transmission outside the dikes, except for some transmission in neighboring mountainous areas. During the annual flooding season, many adult snails are drowned, leaving only the young, which remain submerged during their early stages of development, often floating upside down, feeding on the surface of quiet water. When the water level drops and land cover emerges, adult snails can be found out of water, and in abundance near water, on shaded moist soil of marshes. Continual changes in water level have resulted in reduced life expectancy for snails in this region, which is considered to be about one year. The marshy islands and flood plains that emerge are used for grazing cattle. An important difference in disease transmission from Sichuan is the hypothesis that buffalo and cattle account for more than 85 percent of the transmission of schistosomes in the Poyang Lake environment.

Landsat TM, Elevation, and Water Level Snail Habitat Model

The Institute of Parasitic Diseases of the Chinese Academy of Preventive Medicine in Shanghai has embarked on a remote sensing study for the Poyang Lake environment. Initially, the goal was to replicate the same sort of fieldwork carried out in Sichuan in order to inform a classification of Landsat TM data. This included the surveying of snails, and the collection of soil samples to better understand *O. h. hupensis* ecology. Although the ecologies are different between Sichuan and Poyang Lake, the same methodology can be applied to distinguish between snail habitats and non-habitats. What is different, however, is the need to understand how habitats evolve over time or, more importantly, for different water levels.

Thus far, the remote sensing group in Shanghai has collected a considerable amount of field data. Between April 1999 and December 2000, snail surveys have been performed at approximately 100 sites. Each site corresponded to a 10,000 m^2 area, in which 20 sample locations were randomly chosen and located with GPS, surveyed for snails, and analyzed for soil properties. Other data compiled include weekly water level data recorded at ten monitoring stations throughout the lake region, and weather data, including temperature, humidity, rainfall, and sunlight hours, for ten counties in the area. Also available, but not yet in a usable format are 1:10,000-scale topographic maps for the area.

Thus far we have obtained six Landsat TM scenes for Poyang Lake. The first two scenes were acquired for April and August of 1998 and correspond to before and after a devastating flood, of a magnitude not experienced in some 40 to 50 years. The August scene represents the highest water levels obtainable in the basin. The next three scenes were acquired in April, September, and November 1999, before and after the wet season. The November acquisition date allowed for the water level to drop to a sufficient level after the flood such that it represents the lowest water level of our four scenes. The latest scene obtained was acquired from Landsat 7 on April 2000, which allows us to compare data from this new sensor with previous data from April 1999.

Areas that remain under water even in the dry season, or above water in the wet season, are too wet and too dry, respectively, to be suitable snail habitat. Hence, a simple comparison of high and low water level scenes can provide a crude map of potential habitat. Once snail survey data have been edited, and soil chemistry analyses finished, the Sichuan methodology can be applied to the Poyang Lake imagery to better delineate between habitat and non-habitat. However, already the Landsat TM data have been used to determine the total area of villages, identify grazing ranges for buffalo, and identify snail habitat within the grazing range. Such snail habitat is influenced by the temporal dynamics of water level and elevation. Areas that are covered for long periods are too wet to support snails, and appear in the imagery as bare muddy soil areas. Areas that remain above the water level for long periods of time are too dry to support snails, and appear in the imagery as sparsely vegetated areas. The middle elevations have the right balance of soil moisture to support snail habitat, and correspond to lush vegetation areas in the imagery.

Conclusions

Although there have been attempts to map schistosomiasis for China at the national level, our hope in this paper is to familiarize the reader with the complexities in remote sensing studies due to differences in snail subspecies, associated ecologies, and differences in disease transmission characteristics. Ultimately, in our work, we hope to produce predictive estimates of the spatial distribution of schistosomiasis. Such estimates are critical for China, particularly because large-scale environmental changes are imminent due in part from the Three Gorges Dam, and from evolution as the country balances massive economic development with a national agenda to reclaim and restore land to its natural condition. We have focused on understanding ecologies that support snails, and have relied on field studies to validate our remote sensing classification work to better understand where and why our classifications are not accurate.

Although the presence of snail habitat is a necessary condition for schistosomiasis transmission, snail habitat prediction is only one component of a more comprehensive GIS for assessing Schistosomiasis risk proposed by others (Bergquist *et al.*, 2000), which may be greatly improved by overlaying distributions of human populations and activity patterns to assess environmental exposure. For example, in the Poyang Lake environment, cattle grazing patterns may ultimately determine what subset of snail area corresponds to positive infected snails that contribute to disease transmission. In the Sichuan environment, transmission is largely related to agricultural practices, which influence human infection through water contact and egg dispersion through fertilization. For example, within areas of the Anning River Valley that have snail habitat the prevalence of human infection varies greatly from below 10 percent to above 70 percent. We believe that spatial relationships between particular land cover, such as crop types and residences, may affect disease prevalence at the county and village level. These relationships may be evaluated through the analysis of high-resolution imagery. We have acquired IKONOS imagery for 20 villages in the Anning River Valley for this purpose, and hope that the information they provide may provide better estimates of schistosomiasis risk in the future.

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