Applying GIS and Remote Sensing to the Epidemiology of Schistosomiasis in Poyang Lake, Jiangxi Province, China

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Abstract

Remote sensing, using Landsat TM imagery, has been used to classify snail habitat in the Poyang Lake marshlands, a vast area of high endemism for schistosomiasis in China (Jiangxi Province). Major findings of the study were: 1. RS images are useful for delineating snail habitat and differentiating snail habitat from total bovine grazing ranges. 2. RS enabled tracking yearly dynamic changes in lake area and snail habitat. 3. Dynamic environmental factors are responsible for the fact that some areas suitable for snails may not have snails one year, but have snails another year. 4. The critical factor for maintaining stable population structure is relative temporal stability in mean low water levels. 5. The TMRC snail survey method, employed twice a year, enables a robust statistical evaluation (especially analysis of variance) of changes in snail population density and patterns of infection over large areas. This snail collecting method involving repetitive random sampling and 4 m^2 frames has resulted in reducing the adverse effects of the severe negative binomial distribution of the snails in the sampling data sets, thus enabling statistical analyses.

I. INTRODUCTION

A National Institutes of Health (U.S.A.) - funded epidemiological study (EPI) is in progress in four villages of Poyang Lake, Jiangxi Province to assess the role of bovines, buffaloes in particular, on the transmission of the human blood parasite *Schistosoma japonicum*. Poyang Lake, the largest lake in China and a major endemic area for schistosomiasis in China, has an area of 4,647 km^2 (Anonymous, 1988), and type I mode of *S. japonicum* transmission (Davis et al., 1999). More than 80 to 90% of its water results from the annual flood (from May-June to September-October) of the Yangtze River and backing up of the Gang River flowing through the lake. During full flood all *Oncomelania hupensis hupensis* (with their schistosome infections) snail habitats are submerged and all human and bovines are removed behind protective dykes. Disease transmission only occurs on the lake marshlands.
The hypothesis is that buffaloes are responsible for the persistence of transmission of *S. japonicum* on the marshlands of Poyang Lake with its 1,125 villages and 220,000 buffaloes, and a human prevalence rate ranging from 5 to 30% (Guo et al., 2001).

The Poyang Lake ecosystem is unique and the basis for the type I mode of schistosome transmission defined in detail elsewhere (Davis et al., 1999; Ross et al., 2001). While considered the largest lake in China , the basin is full only during the seasonal annual floods driven by the June monsoons, the flooding of the Yangtze River and the back up of the four major rivers flowing through the basin, of which the Gang River is dominant. During the annual flood all humans and animals are sheltered behind dykes. In the fall and winter, the lake loses more than 85% to 90% of the water. As floodwaters retreat, bovines move out onto the vast emerging marshlands to forage. The marshlands are habit for the snail intermediate host, *Oncomelania hupensis hupensis*. All infections occur on the marshlands beyond the dykes. Infection occurs when a mammal enters water and a larval stage shed by the snail penetrates the skin of the mammal. There are thus two periods for infection to occur; when the floods retreat in late September or October (at times as late as November) until the ground becomes too cold for the snails to be active (10^{0}C), and spring after it warms up enough for snails to be active and before the floods cover the marshlands (May or June). The uniqueness of mode I transmission is the combination of 1) the unique ecology where bovines apparently are responsible for the existence of schistosomiasis; 2) the annual floods that impact the life cycle of the snail host; 3) the snail being a subspecies very genetically divergent from *O. hupensis robertsoni* transmitting *S. japonicum* in Yunnan and Sichuan, highland areas west of the Three Gorges of the Yangtze River; 4) the effect of the dynamic ecosystem on the population genetics of the snails.

Remote Sensing (RS) and Geographic Information Systems (GIS) are being employed as the most feasible way to analyze Poyang Lake to determine the distribution of snail habitats throughout the vast ecosystem, to assess the changes of emergent marshland as lake levels fluctuate from year to year due to the hydrological dynamics of the Yangtze and Gang rivers that are influenced by the timing and amount of rainfall of the annual monsoon, to asses the differences in cattle grazing

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ranges contrasted with that subset of range suitable for snails, to create a baseline database of the environmental and hydrological factors that currently impact the lake basin in relationship to snail habitats and disease transmission, to assess the dynamic changes that will occur throughout Poyang Lake with the completion of the filling of the reservoir behind the Three Gorges Dam (TGD) of the Yangtze River. On a finer scale, GIS and RS are used to aid the EPI of the four villages with emphasis on monitoring the effects of lake-level changes on snail habitats and optimal transmission sites for disease transmission known as Hot Spots (HS).

The objectives of this paper are: 1) We provide background GIS data for Poyang Lake. 2) Classified RS images are used to determine the areas suitable for snails throughout Poyang Lake and to assess how these areas do change over short periods of time (both seasonal and annual changes). 3) We demonstrate how RS images enable distinguishing snail habitat from non habitat in the cattle grazing ranges. 4) GIS and RS are combined in three of the EPI villages to demonstrate the temporal environmental dynamics on snail densities and frequencies of infections on the marshlands of the villages with respect to HS and non-HS habitats.

II. IMAGE PROCESSING AND SNAIL SAMPLING

RS image classification

Landsat TM images (procured from China's Remote Sensing Satellite Ground Station-Beijing) for 6 April 1999, 11 November 1999 and 29 January 2001 were used in association with land survey data from the same time periods to identify and track changes in snail habitats. Images were analyzed using PCI v6.2 software (PCI Geomatics Enterprises Inc., Ontario, Canada). The 6 April 1999 image was geometrically corrected by UTM projection at 30 x 30 m resolution. Forty ground control points were obtained from topographic maps (1:10,000) where GPS data were subsequently obtained to rectify the image. All other TM images were registered to the April 1999 image with a root mean square error (RMSE) of < 1 pixel using 40 tie points. Bands 3-5 were used to classify the images (unsupervised method) using the ISODATA clustering algorithm. Empirical evidence shows that using more bands creates error. Additionally, these bands were used successfully by Lin et al. (2001) in attempts to classify snail habitat. This procedure enabled identification of distinct land cover types visible in each seasonal image. Having experimented with 10 to 20 clusters, the resulting preferred number was 15 with 100 iterations. Field data, collected during the same time period the image was taken, were used to determine which of the land covers were most associated with snail habitat. Each ground survey site corresponded to a 3 x 3 pixel area in the classified image. The April image was also examined using channels 2, 3, and 5 for visual examination (raw image, not classified) as shown in Figs. 3, 5. Sensitivity and Specificity indices for the image classifications for the three images were calculated and tabulated.

Snail survey

A detailed survey of the distribution of snails and percentage of infected snails on both islands and floodplains of Poyang Lake 20 years ago was printed and bound (Editorial Committee, Jiangxi Institute of Parasitic Diseases, Nanchang, 1985). That report listed and provided maps for 556 islands and floodplains with the lake basin divided into quadrants (centered in the geographic middle of the lake; 116^0 13' E, 280^0 55' N) (Figure 1, Table 1).

In this study, we chose 100 areas to survey based on the historical record for having snails, for not having snails yet seemingly appropriate for snails and situations where snails could not possibly live (e.g. oil plant field, dyke top, mud flats, sandy bluffs, etc.). The historical sites to be revisited were selected to be scattered throughout the lake basin. Also included in this number were the EPI sites from the villages of Jishan, Hexi, Xinhua, and Dahuang. The sites were selected from islands and flood plains (574 discernable land mass units [LMUs]): 50 from previously known snail habitats, 25 from non-snail habitats and 25 from sites that could have no snails (e.g. oil plant fields, etc. see above). Each of the 75 LMUs that could potentially have snails was examined for presence of snails. Where snails were found, a 10,000m^2 area (the square or SQR) was marked off and that area subdivided into 100 10m x 10m numbered cells (for example, each small square labeled A to E, F, or G in Figs 3 to 5 represents a SQR. Twenty of the cells were selected at random and in the center of these all snails were collected from a 4m^2 frame (see Davis et al., 2002). A Geographic Positioning System (GPS) reading was recorded from the center of each frame collected. All snails were examined for infections. Snail density and frequency of infections were calculated as in Davis et al., 2002. The coordinates of the center of SQRs were recorded using a GPS instrument.

Data collected from each site were: soil sample for soil chemistry, soil saturation, pH, incident light at "snail level", incident light above "snail level", humidity at snail level and above, and temperature above, at and in the soil beneath snail level, land use. Macro-environmental data from 1996 on included rainfall, incident radiation, humidity, temperature, and water levels from 10 hydrological stations.

Data presented here for the EPI sites are from Hexi (10 sites), Jishan (7 sites), and Xinhua (5 sites). Collections from Hexi and Jishan administrative villages were from post-flood and pre-flood collections over seven seasons from November 1998 to November 2001; those from Xinhua were from five seasons from November 1998 to December 2000.

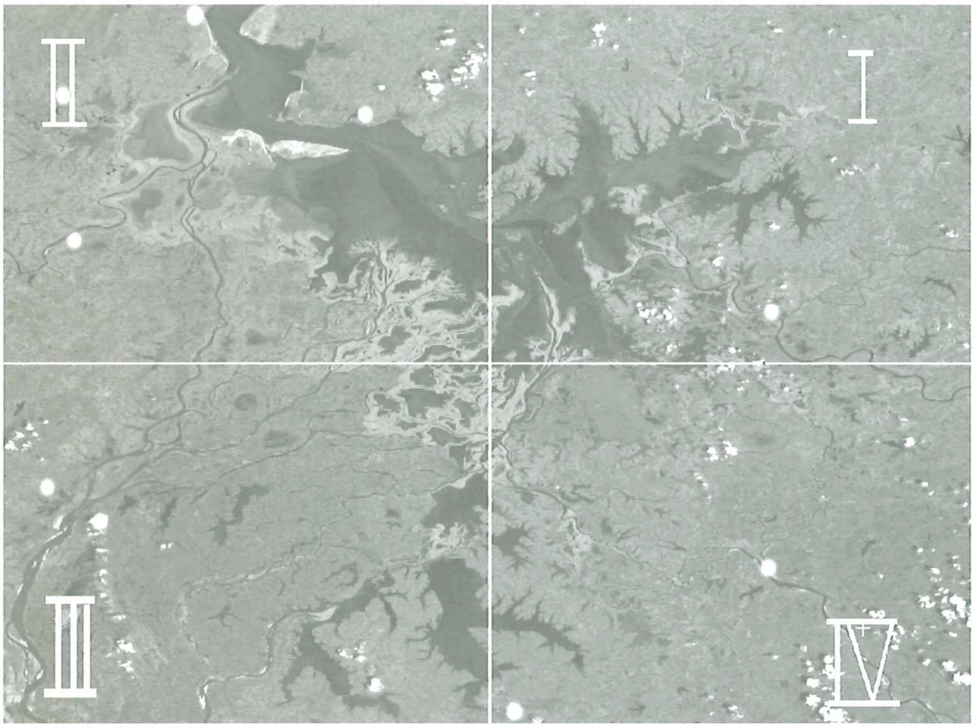

Figure 1. Poyang Lake divided into quadrants. White dots = weather stations.

III. RESULTS

Classified image: sensitivity, specificity, changes in snail habitat

In the classified image (Figure 2), areas outside the lake basin were masked out. The lake is in an N – S orientation with the outlet to the Yangtze River at the top of the figure. The green areas are potential snail habitat (grasslands and sparsely covered grass lands) and are primarily along the western side of the lake. Calculations based on the April 1999 image (low water) show that the lake proper (exclusive of upper reach damned areas) has an area of 3,481 km^2 of which 54% is flood land and 19% snail habitat. The recent collection data show that 36% of the LMUs that historically had snails did not have snails by 2000 (Table 2) and that 40% of the LMUs that historically did not have snails gained snails by 2000. Classification sensitivity ranged from 90.0 to 95.6 % while

Table 1. 1985 LMU data for Poyang Lake by quadrant (from writing committee, Jiangxi Provincial Institute of Parasitic Diseases)

	QUADRANTS					
	I	II	III	IV	TOTALS	
No. LMU	126	211	48	173	558	
average elevation (m) ± stdv +	14.4 ± 0.85	14.9 ± 1.12	14.78 ± 1.2	15.3 ± 1.09		
range for low points	(13.0 - 18.6)	(11.6 - 17.3	(13.0 - 18)	13 - 22.5		
average elevation (m) ± stdv +	15.8 ± 1.07	16.03 ± 0.92	16.23 ± 0.91	16.6 ± 1.21		
range for high points	(13.4 - 19.0)	(14.0 - 17.8)	(14.6 - 18.6)	(13.8 - 25.5)		
average area/LMU ± stdv (km^2)	1.66 ± 1.95	1.86 ± 3.29	0.88 ± 1.12	1.1 ± 1.31		
# islands	85	150	35	158	428	77%
no. with snails	56 (66%)	95 (63%)	27 (77%)	120 (76%)		
no. without snails	29 (34%)	55 (37%)	8 (23%)	38 (24%)		
# flood plains	41	61	13	15	130	23%
no. with snails	26 (63%)	45 (74%)	6 (46%)	10 (67%)		
no. without snails	15 (37%)	16 (26%)	7 (54%)	5 (33%)		
Mean no. snails/meter square ± stdv	5.23 ± 30.05	3.77 ± 8.39	3.64 ± 11.17	6.18 ± 19.25		
% Infected snails	0.23 ± 1.56	0.73 ± 1.5	0.0023 ± 0.02	0.18 ± 1.01		
density of infected snails	0.01 ± 0.05	0.02 ± 0.05	0.00001	0.02 ± 0.09		

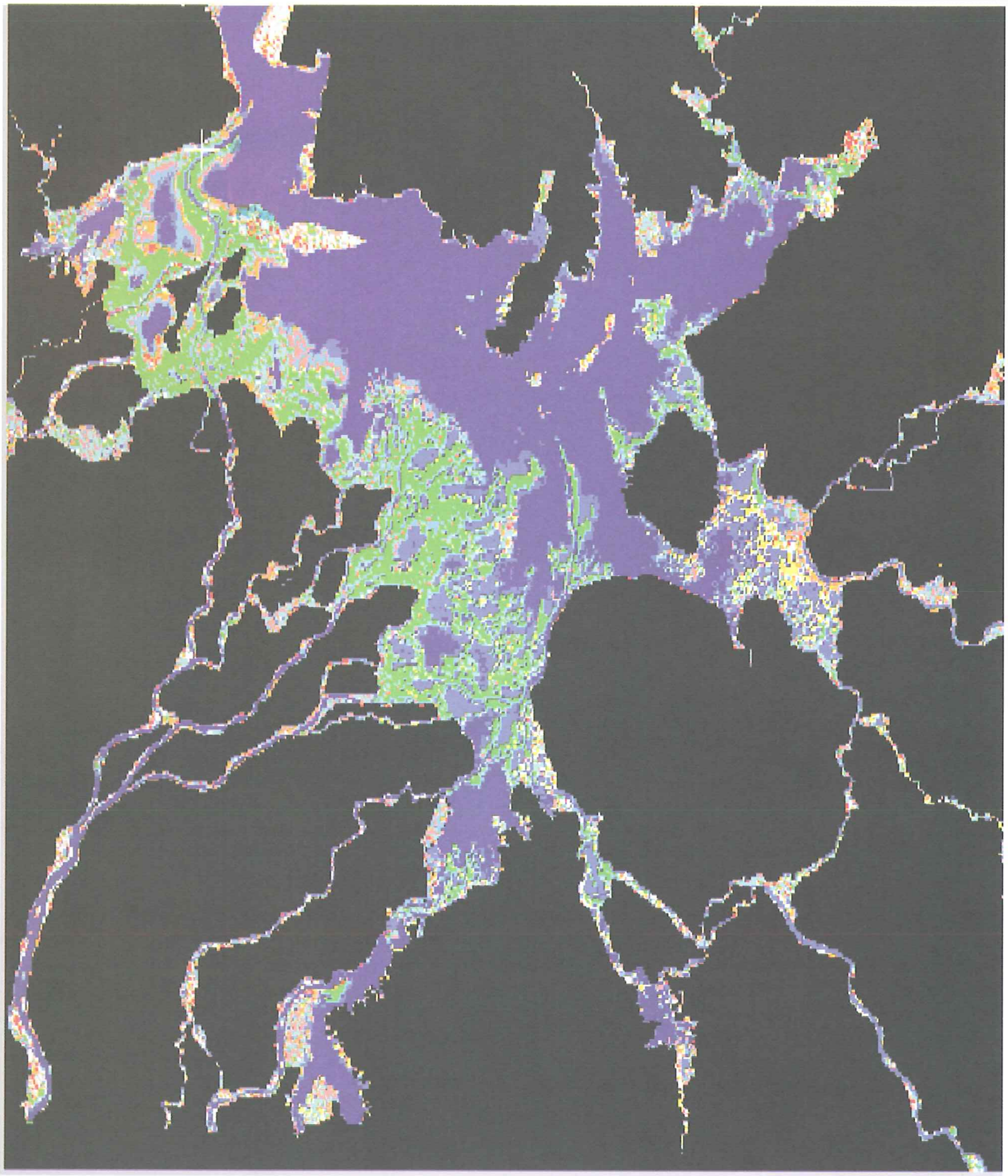

Figure 2. Classified image of Poyang Lake at low water in N-S alignment. Bright green = grasslands suitable for snails; blue = water; white = sand. Black = masking of all lands outside the lake basin. Pinkish = elevated land-mixed vegetation/farm use. Bright Yellow = mud and/or agricultural land.

specificity was much lower, ranging from 61.1 to 68.3% (Table 3). Estimated snail habitat area (based on pixels) increased from 632.4 km^2 in April 1999, to 695.99 km^2 in November 1999 to 762.8 km^2 in Dec 2000, total gain of 130.4 km^2 or about 21%. Snail sites were primarily associated with grassland (covered by dense or tall grass; grass coverage > 50%) and secondarily associated with sparsely covered grassland (short grasses, or sparsely distributed grasses with grass coverage < 50%). Together these two conditions accounted for > 90% of sites with snails. Examination of sites that were entirely unsuitable

Table 2. Comparison of historical data with current survey data for LMUs with or without snails.

Historical Sites (pre 1900)	Survey 1999 - 2000	
	+ snails	- snails
Had (50)	32	18
Not Have (25)	15	10
Totals	47	28
Could not have (25)		25

for snails yielded no snails. Sites that classified as good snail sites but which did not have snails when examined accounted for 31% - 39% (commission error). Reasons for this are discussed below.

Image interpretation and optimal snail habitats- EPI village LMU

Visually classified and habitat-selected classified images for Jishan Administrative Village (Figures 3, 4) enable demarcation of snail habitat within the cattle grazing ranges. Buffaloes can (and do) graze under water where *Oncomelania* snails cannot long survive. The bright blue areas set off from the fringing dark blue or blue-black are suitable for snails as they are above grasses covered to various depths by water (dark blue). The white areas are sand. The grazing range of buffaloes, grading from rich grass lands down to sparse grass and mud, including grass covered by a sheet of water = 16.4 km^2 (areas 2, 3, and 4; Figure 4). Within the entire buffalo grazing area, snail habitat (area 2, Figure 4), areas of grass land free of standing water = 10.2 km^2 or only 62% of the total buffalo grazing range.

Soil chemical data showed Poyang Lake to be rather uniform for areas that were suitable for snails both historically and presently, including areas seemingly excellent for snails but without snails at the time of collection. The soil data are published elsewhere (Seto et al., 2002).

Frequency of infected snails. demonstrating temporal changes in areas devoid of snails, density of snails and frequency of infected snails.

Xinhua Village grazing land is shown in Figure 5. The squares next to the letters are the collecting sites = SQR at sites A to E. The 1.18 km^2 tongue of snail habitat (black) of the village is bounded by the stream between SQRs E and A on the west, bluffs running from E – D –C on the north, the river to the south, and the incursion of shallow lake water at the eastern end. Based on the number of frames collected for snails, there was a dramatic change in % area without snails over the five seasons, ranging from about 90% in Nov 1998 to < 5% in Dec 2000, (Figure 6). The density of snails likewise changes dramatically in the five sites as seen in Figure 7.

There were virtually no snails to be found during the first two seasons. At sites A and B, closest to the river, there was a rebound at site A in May 1999 and at both sites A and B there was an immense increase in density in December 2000 with densities exceeding 90 snails per m^2. In May 1999 a Hot Spot was located at site E, an area closest to the bluffs and the villages situated on the bluffs. Overall, there was a highly significant increase in snail density from season 1 to season 5 ($P<0.0001$).

The frequency of infected snails on the Xinhua grazing land is shown in Figure 8. The sharp increases at A and C are artifacts due to the chance occurrence of finding two or so infected snails among very few snails collected. No infected snails were found at A or C thereafter. A consistent pattern of finding numbers of infected snails was found at site E. While there was a significant drop in infections at site E in November 1999 (the reason for this drop is not known), thereafter there was a significant increase in frequency to December 2000 ($P = 0.003$). Overall, comparing frequencies at time 2 (first time site E was collected) with time 5, there was no significant change ($P = 0.33$).

Coordinate based assessment of changes in snail density and frequency of infection.

By recording the coordinates of each frame collected from the 10,000 m^2 sites, it is possible to project temporal changes in snail density and frequencies of snail infections on the village's snail habitats and buffalo grazing ranges. An example of these projections (Figure 9) enables, at a glance, an understanding of where HS are located, which parts of the grazing ranges are unsuitable for snails, and which areas of the grazing ranges either do not have infected snails or have negligible or sporadic infections. In the example shown, snail densities are highest at the right top blue site in Jishan with an average of 26.6 snails / m^2 while the site to the far right had only an average of 7.15 snails/m^2. However, sites with infections (right graph) are prominent at all three sites to the far top right (blue areas, Jishan) with frequencies of infections ranging from 7.8 infected

Table 3. Sensitivity and Specificity of image classification

Image Dates	Survey Dates	LMU Surveyed	+ snails	- snails	Sensitivity %	Specificity %
Apr-99	Apr-99	44	25	19	90	61.1
Nov-99	Nov-99	23	11	12	95.6	63.9
Jan-01	Dec-00	25	8	17	94.5	68.3

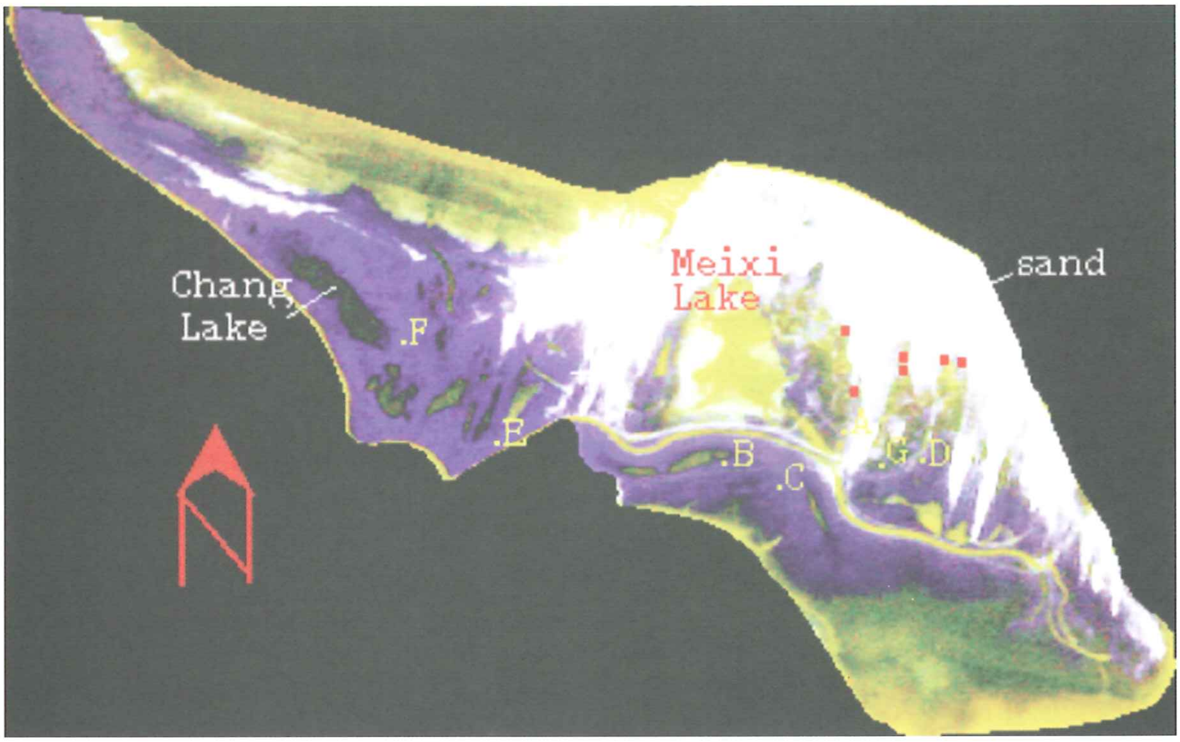

Figure 3. Unclassified RS image of Jishan Village LMU. B – E =1.8 km. Bright blue = snail habitat; dark blue to blue-black is grass covered to various depths by water and thus unsuitable for snails. Yellow is silty water; green is mud flat or shallow water over mud; white = sand. Black splotches in the marshland =shallow lakes with grass or pools of water (e.g. Chang Lake). Red squares = natural villages. Yellow letters are sampling sites. White = sand. Each small yellow square beside the lettered labels that indicate a sampling site is the location of a 10,000 m^2 Square (see text for details).

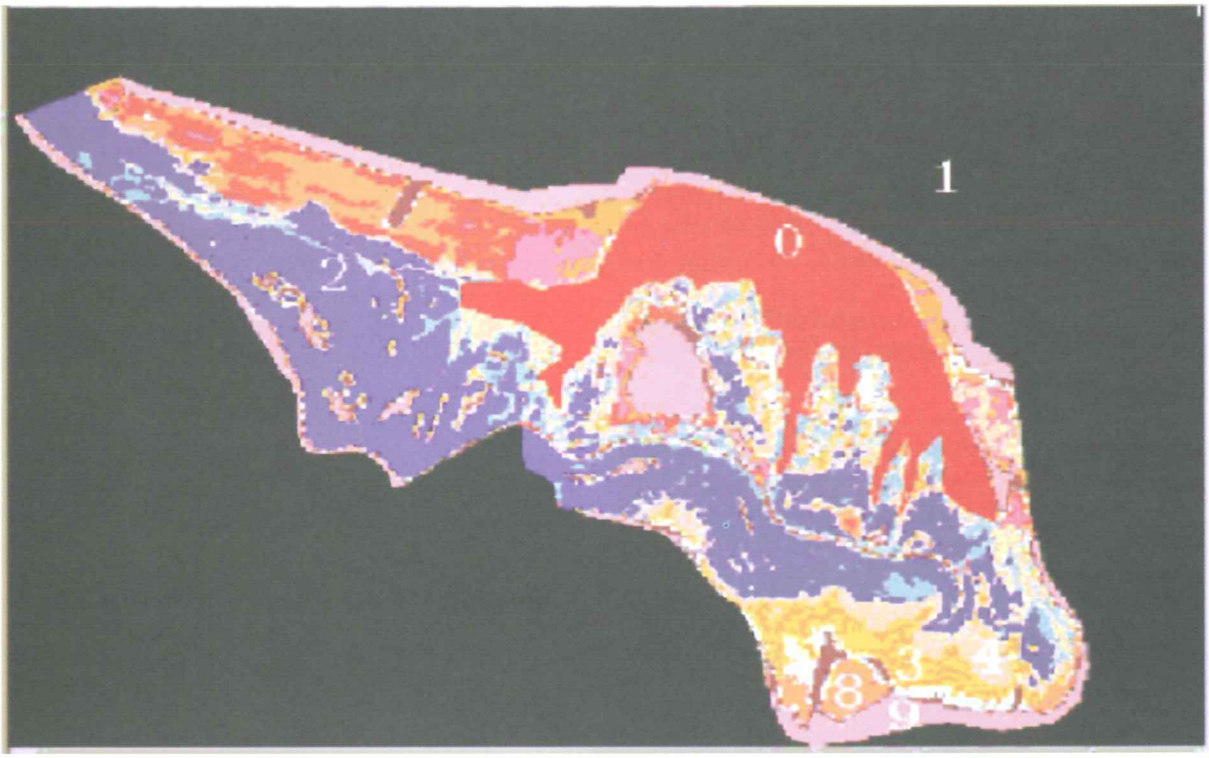

Figure 4. Classified image (using bands 3, 4, and 5). 1 = mask out areas surrounding the village. Bright blue (2) = snail habitat; 2,3,4 = cattle grazing range. 3 (yellow) = mud/agricultural land; 8 =mud; 9 = water.

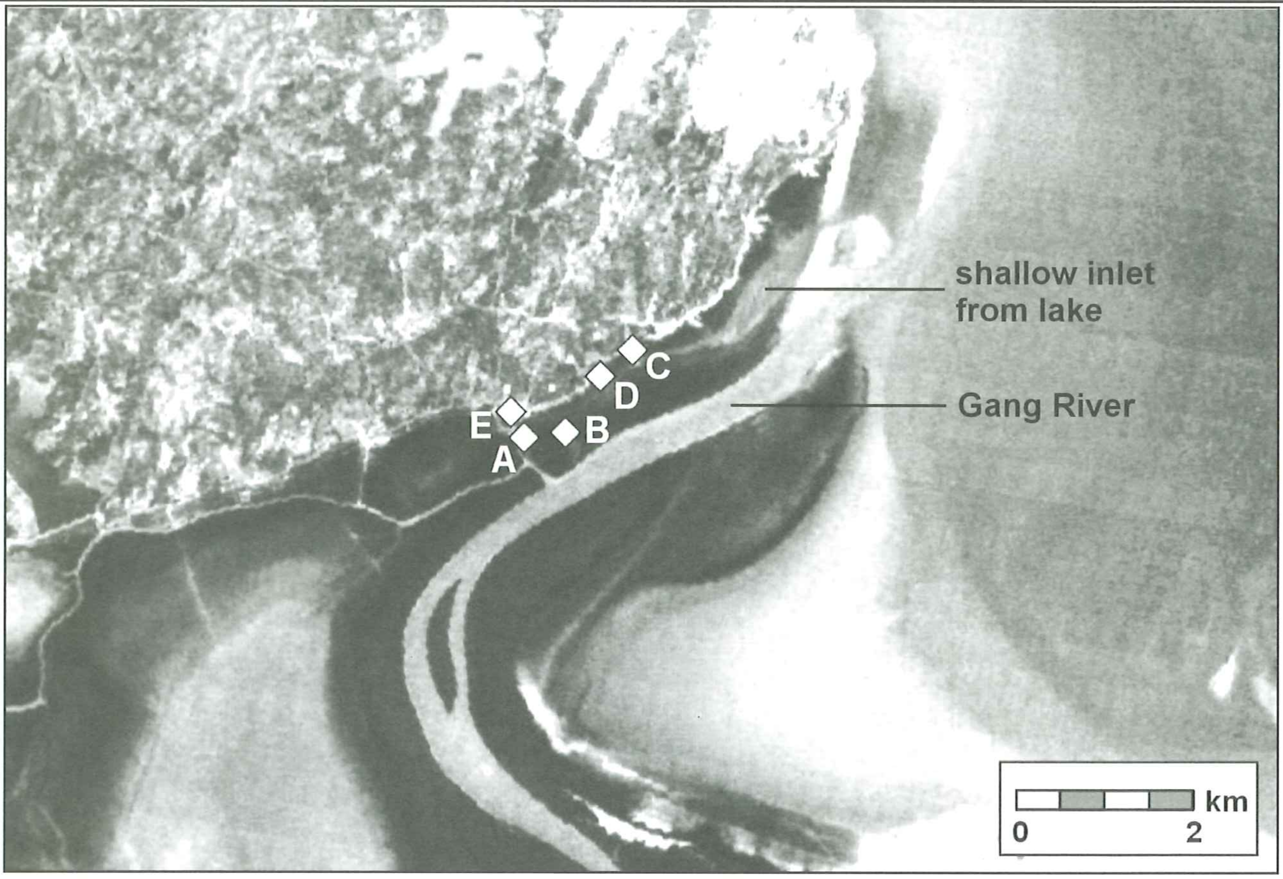

Figure 5. Unclassified image of Xinhua Administrative Village, snail habitat (black) sliver of habitat bounded by the Gang River, site A, the highlands and bluffs (above sites C, D, E) and the shallow inlet from the lake. Site E is a Hot Spot. The light areas under the scale bar is the shallow water of the lake. To the left of the Gang River (lower left) are water and shallow water over grass.

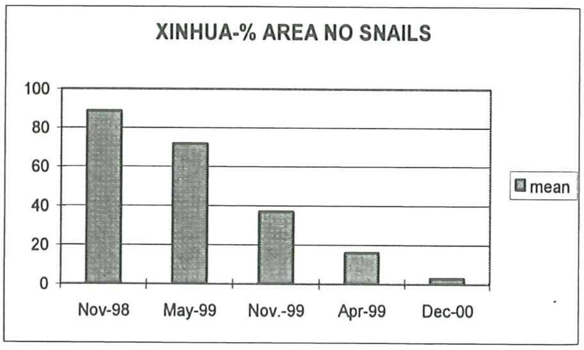

Figure 6. Percentage of grazing area averaged over all sites that did not have snails in each of the five seasons.

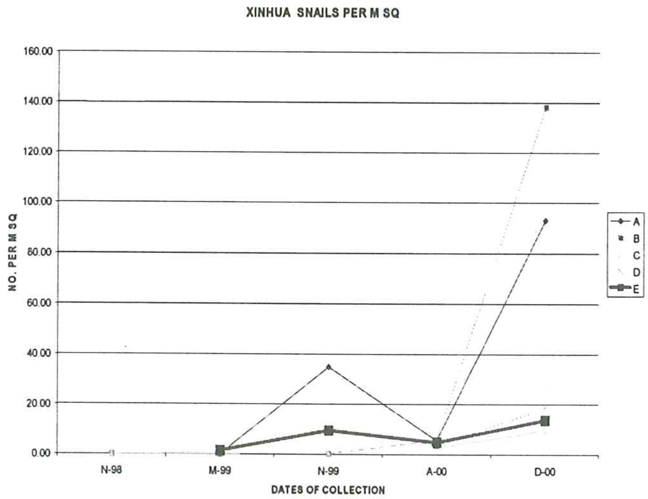

Figure 7. Number of snails per m^2 from five sites on the Xinhua Village buffalo grazing range. Site E is a Hot Spot.

snails/1000 to 34.5 / 1000. Other sites within Jishan had no infections. This is contrasted with scattered sites in Hexi (red spots) that had infected snails in 7 of 9 sites with infections ranging from 1.4 per 1000 to 18.7 / 1000.

IV. DISCUSSION

Summary of major findings

There are several major finding presented here. 1) RS has enabled tracking dynamic changes in the lake area, and the yearly changes in the area of flood lands. 2) RS images clearly are useful in delineating snail habitat. 3) Dynamic environmental factors are associated with the reasons why some areas suitable for snails do not have snails at the moment

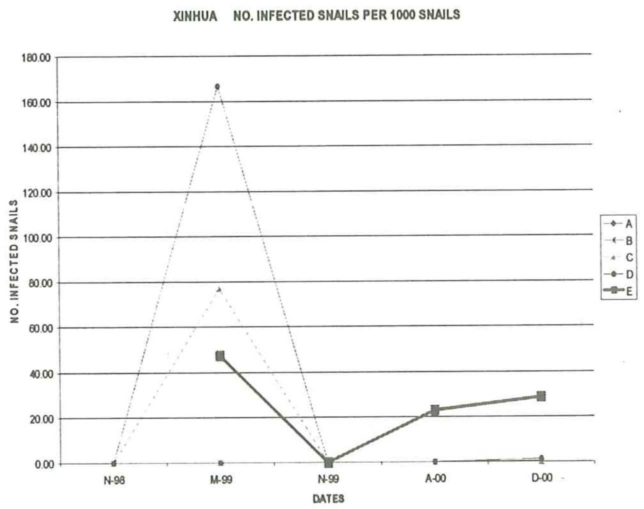

Figure 8. Frequency of infected snails (number per 1000 snails) at sites in Xinhua village's buffalo grazing lands.

of survey, yet at other times will have snails. 4) The critical factor for maintaining stable snail population structure is relative temporal stability. Stability requires low variance in lake level from year to year relative to the elevation of land above mean low water. 5) The TMRC snail survey method coupled with RS, GPS and GIS enables tracking changes in snail population density and patterns of infection over large areas. This snail collecting method involving repetitive random sampling and 4 m^2 frames has resulted in reducing the adverse effects of the severe negative binomial distribution of the snails in the sampling data sets, thus enabling statistical analyses. In most instances comparable statistical analyses are not possible using the Chinese traditional method of a kuang frame (0.11 m^2). The use of a kuang frame is standard procedure for snail surveys as outlined in the Minister of Health's nadbook for schistosomiasis control. 5) The TMRC method enables tracking Hot Spots of infection.

Review of areas of flood lands and snail habitat.

There have been various estimates of snail habitat over time. In the Anonymous 1985 report, there were about 834 km^2 for the 558 LMUs reported in their survey. Of these, 77% were islands and 23% flood plains (called beaches in the English – language papers published by Chinese epidemiologists). These areas are all considered to have potential to have snails. The 834 km^2 is only about 9 % larger than the 763 km^2 we calculate for Dec 2000.

In the 1998 report (Anonymous, 1998) the amount of flood lands were estimated as 12,222,910 Mu of which 946,377 Mu (7.7%) had snails (Anonymous, 1988). As one Mu = 666.666 m^2, a km^2 = 1,500 Mu. Thus the 1988 publication reported 8,148.6 km^2 of flood land of which 630.9 km^2 had snails. Our new April 1999 data are not significantly different from the 1988 data for areas with snails.

Most recently, Lin and Zhang (2002) reported that historically (pre 1985) snail habitat was 1,400 km^2, much more than the total LMUs reported in1985 (834 km^2), of which 23% to 54% did not have snails (Table 1). That area would have been equal to 30% of the current lake basin area (4,647 km^2)! However, long before the decade of the 80s, when protective dykes were not fully surrounding the current lake basin, the spread of water and thus snail habitat would have been much more pervasive than today.

Classification of snail habitat, sensitivity, and impact of environmental changes

RS images do enable tracking the changes in habitat areas with the changes in lake levels brought on by fluctuations in the amount of rainfall, the timing of the beginning of the annual monsoon, the severity of annual flooding and duration of flooding. Temporal environmental changes affecting Poyang Lake are enormous, and these in turn have a profound impact

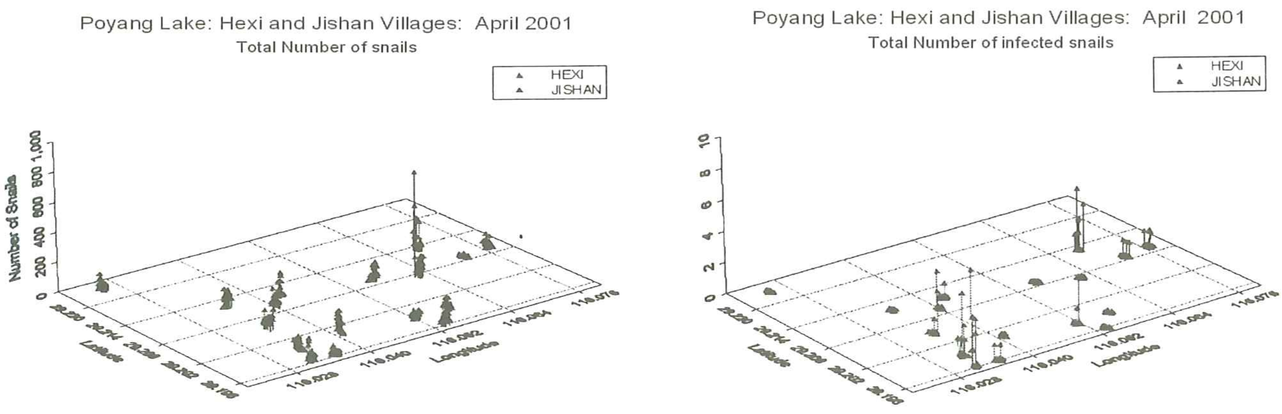

Figure 9. Coordinate-based 3-dimensional plots of numbers of snails (left) and number of infected snails (right) collected, in April 2001, from each 4 m^2 frame (with snails) within the 10,000 m^2 representative areas of each village. Coordinates were based on GPS readings at the center of each frame.

on the snails that have an unusual biology.

Oncomelania hupensis hupensis is an amphibious snail that, as an adult, lives in the ecotone between water and dry land. If adults are inundated too long, they will drown, a fact made use of to destroy *Oncomelania* snails where this strategy can be brought to bear. The snails thrive best on moist silt-rich soil in a humid environment under thick grasses and other vegetation (Davis et al. 1999, 2002). These conditions in Poyang Lake are found when lake levels are such that the snail habitat zone is between 14m and 17m elevation (elevation calibrated to the Yellow Sea) (Anonymous, 1988). Unlike the mountains in Sichuan Province (where *O. h. robertsoni* lives), the soil in the marshlands of Poyang Lake is a uniform depositional soil with no significant differences among habitats seemingly inhabitable by snails, but where snails may or may not be found (Seto, et al., 2002).

Why, then, were specificities in the classification process of the RS images rather low (61 – 68%)? Why would a LMU appearing to be a perfectly good snail habitat in an image and on the ground have no snails? The vegetation, soil moisture, vegetation, humidity were suitable for snails, and soil chemistry has proved not to be a factor. The predominant reason is associated with temporal environmental changes driven by water level changes and factors associated with these changes. As seen in Tables 1 and 2, comparing LMUs in 1985 and today, many sites that historically did not have snails, do so today, and the opposite holds true also. The only changes affecting these areas are temporal environmental changes, especially lake level changes.

We document one LMU where we have data demonstrating this point. In 1988 China suffered the worst flood in some 40 years and this flood severely affected Poyang Lake (see Davis et al., 1999). The floods came early and left late, filling Poyang Lake to the tops of the dykes. Areas of lowest elevation were especially affected adversely. Xinhua Village's grazing lands were (Figure 5) such an area. The elevation of the grazing ranges was at the lowest possible where snails could still survive.). Sites A and B, (< 13.5.m elevation) were close to the Gang River that had severe currents brought on by severe flooding. Historically, these sites had high-density snail populations. After the flood subsided, in November 1998, the entire area including sites A-D was swept clear of snails. This is clearly shown in Figs. 6 and 7. Sites A and B were particularly devoid of snails. Over five seasons snails gradually spread out over the grazing land again so by season five, virtually all the land had some snails.

Snail density in Xinhua was negligible for two seasons. There was a sharp increase in snail density at site A; one during season 3 and the other during season 5. The sharp spikes in snail density at sites A and B, closest to the Gang River, are exceptional. The reason for these sharp increases cannot be attributed to the intrinsic rate of natural increase in these snails, but to another factor, importation. *O. h. hupensis* is readily transported, and in large numbers, during annual floods (reviewed in Davis et al., 1999, 2002). These snails are floated on the surface waters. With receding floods, large numbers of snail are frequently deposited on flood plains of rivers such as the Yangtze and Gang.

Following the great flood of 1988, the following year was also a high-water year with elevated levels and an extra long season for the flooding. In following year there was less water and thus the marshlands gained area, the 21% gain from 1999 to December 2000. Thus there is immense flux in available marshlands dependent on water levels. Too severe a withdrawal of water vastly increases emergent land but has an obvious negative impact on snails that require a tightly defined ecotone for reproduction and survival. The 21% increase in available snail habitat from April 1999 to January 2000 is due to the fact that in 1999 it was still a severe flood year, though not nearly as bad as in 1998. It was not until 2000 that the lake reverted to the more usual level fluctuations.

On a larger time scale, there is abundant evidence that the lake's mean low-water level has been constantly raising over the past decade or more within the rings of the complete dyke systems. Evidence for this is seen in Jishan Village at sites G and D near the natural villages. Here, farmlands had to be abandoned as evidenced by marsh grasses growing on old, once-cultivated paddy fields.

In summary, for our purposes, flood lands are divided into three types: 1) the mud flats grading into areas supporting some grass; 2) cattle grazing range that grades from water-covered grasses throughout the marshlands supporting grasses of all types; 3) snail habitat where the land, within the cattle grazing range, is dry enough to support snails. Marshlands that appear suitable for snails based on remote image classification may indeed be suitable at that moment for snails. However, the above example in Xinhua Village demonstrates the dynamic changes in presence or absence of snails and in density of snails associated with environmental factors. The example from Jishan Village demonstrates the longer-term changes affecting snail habitat, both creating and destroying habitat.

Infected snails and Hot Spots

There is no correlation between frequency of infection and snail density. Where the EPI study has been ongoing for seven seasons, the correlation between snail density and frequency of infections for all sites was r = - 0.1888 in Hexi Village (N = 61) and -0.2095 in Jishan Village (N = 48). When only SQRs with infected snails were considered, r = -0.4551 in Hexi (N = 29) and -0.3167 in Jishan (N = 23). If anything, there is the weakest of trends for a decreased frequency of infection with increased snail density.

As seen in Figs 7 and 8, there was only one Hot Spot in Xinhua Village, site E, located at the base of the bluffs. There were virtually no infections anywhere else (the sharp peaks at sites C and D in season two were artifacts of the chance finding of one or two infected snails among the very few snails found and collected). The density of snails at site E never exceeded 18 per m^2 and was mostly <10 per m^2. By contrast, the dump of snails at sites A and B during season five yielded > 90 snails per m^2 and these were not infected.

What densities of snails are usual for these marshlands? As seen in Table 1, using the traditional kuang-method of collecting (see Davis et al., 2002 for an explanation of the traditional method), the mean number of snails per m^2 ranged from 3.6 ± 11.2 to 6.18 ± 19.3 depending on the quadrant in the 1985 work (Anonymous 1985). Because of the high negative binomial distribution of these snails and the use of the small area kuang frame to collect them, the standard deviation can be extremely high compared to the mean, e.g. 5.23 ± 30.1 for quadrant 1 LMUs. These densities are low on the scale of values for negligible, low, medium and high densities given in Davis et al. (2002). By contrast, > 90-snails/ m^2 is very high density.

So what makes a Hot Spot? These are small areas where there is close association of man with water buffalo and optimal snail habitat. These have been defined and discussed in detail in Davis et al. (2002). In Xinhua, the area is where people come down from the bluffs onto the marshlands with their buffaloes. It is a bottleneck where buffaloes and man pass back and forth, the buffaloes twice a day (moving down and onto the marshes for a day's foraging; then driven back to the villages for the night by the cowboy). These HS cannot be located by large-scale RS, but can be tracked using IKONOS technology once they are located.

RS, GIS and ecological zones

An epidemiological analysis of disease transmission in Poyang Lake requires the following: 1) knowledge of the different ecological zones used by cattle for grazing, and the subset of those zones that are hospitable for snails; 2) impact of differing ecologies on snail density and distribution in relationship to frequency of snail infections; 3) the location of HS and factors that keep HS active; 4) a data set that can be analyzed statistically.

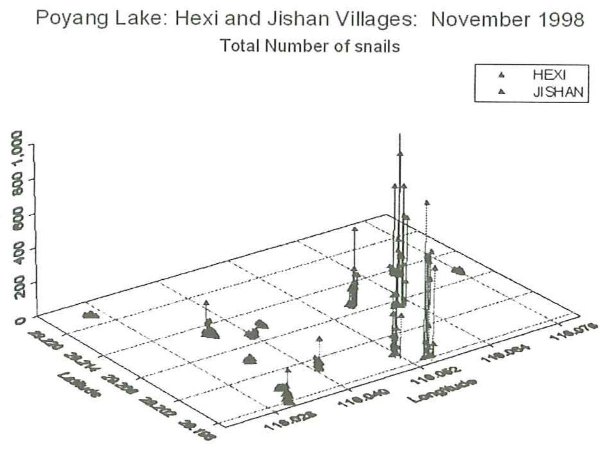

Figure 10. Total number of snails in each site collected in November 1998. One collection had > 1000 snails (blue line without arrow top, upper right corner)..

The GIS database involving seven seasons has demonstrated that the high-density zones for snails are in the right half of Figure 10. Quadrant II of Figure 10 (top left) is too wet for snails to thrive. Quadrant III of Fig 10 is higher elevation, rather dry with many sections with sparse grass, thus not optimal for snails. Large flat areas with numerous pools of water, at optimal elevation and with dense grass are optimal for snails and have the highest density of snails (quadrants I and IV). However, persistent HS are correlated with short distance from villages and human activity combined with routine convergence of buffaloes in those spots (Davis et al., 2002). Contrary to intuition, frequencies of infections are not correlated with the highest density snail areas.

The data also show that while snail density has significantly decreased since 1998 (compare Figure 10 for November 1998 with Figure 9 top from April 2001) especially in quadrants I and IV, HS persist. The cause for the decrease in snail density is under investigation.

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