The Geographic Understanding of Snail Borne Disease in Endemic Areas Using Satellite Surveillance

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The current status of research on use of earth observing satellite sensors and geographic information systems for control program management of schistosomiasis and fascioliasis is reviewed.

Key words: *Schistosoma* - *Fasciola* - epidemiology - geographic information systems - satellites - *Biomphalaria* - *Bulinus* - *Lymnaea*

Geographic information systems (GIS) technology provides a powerful new tool for epidemiologic studies on vector-borne diseases with strong environmental determinants. By use of statistical and image analysis methods GIS allows computer based analysis of multiple layers of mapped data in digital form, including earth observation satellite data, agroclimatic databases, and maps of host populations, vector distribution and disease prevalence. GIS data layers are registered to the identical scale and geographic projection of a reference base map. This allows analysis of all information by location, including descriptive data sets that are 'attached' to specific locations or areas (Burrough 1986).

Once created, GIS provides a dynamic, easily updated mapping system that can be used by health management officers to plan and monitor control programs. By virtue of its potential to 'match' the relative suitability of various environments to the life cycle and transmission dynamics of host-parasite systems, GIS provides a new way to address classic concepts of 'landscape epidemiology' and the essential nidality of disease (Pavlovskii 1945). Recent applications include schistosomiasis (Cross & Bailey 1984, Malone et al. 1994), fascioliasis (Zukowski et al. 1992, 1993, Malone et al. 1992), rift valley fever (Linthicum et al. 1987), African trypanosomiasis (Rogers & Randolph 1993) and east coast fever (Lessard et al. 1990).

Digital data from several polar orbiting and geostationary (fixed view) earth observation satellites systems are available for purchase by investigators for development of GIS models of disease. Three of the most commonly used are listed in Table, with earth surface resolution for each pixel (picture element) and the swath width of imagery that is available. This review focuses on the potential for application of satellite sensor and GIS technology in control programs for two snail borne diseases, schistosomiasis and fascioliasis.

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TABLE

Data collection interval, resolution of each pixel (picture element) and swath width for data from polar-orbiting satellites commonly used for remote sensing and geographic information systems

	Interval	Resolution	Swath
AVHRR	12 hours	1.1 km	2800 km
Landsat MSS	18 days	79 m	185 km
TM	16 days	30 m	185 km
SPOT	26 days	20 m (infrared)	60 km
		10 m (visible)	60 km

SCHISTOSOMIASIS

Dramatic recent success in schistosomiasis control has been realized in Egypt by a campaign of mass chemotherapy supplemented by molluscicide use and a unique public education program (El Khoby 1994). Schistosomiasis typically has a patchy distribution in endemic areas. This has been attributed to environmental effects, local snail-parasite genetic compatibility or to sociologic factors, especially agricultural practices or the proximity of a particular community to strong transmission foci. Identification of environmental indicators of high infection risk may facilitate provision of more frequent chemotherapy and focal molluscicide for areas of high prevalence that may serve as reservoirs for well controlled areas. Future success in the consolidation and maintenence phases will depend on broader intervention efforts to target areas where high-intensity *Schistosoma mansoni* infections occur and on development of cost-effective strategies for eliminating residual foci of *Schistosoma haematobium*.

Polar orbiting environmental satellites operated by the U.S. National Atmospheric and Oceanographic Administration (NOAA) acquire daytime and nighttime thermal infrared measurements of the earth's surface around the world, at 1.1 km spatial resolution. This sensor has an across track swath 2800 km wide beneath the satellite, measuring daytime reflected solar radiation in the visible and near mid-infrared spectral bands and radiation both day (Tmax) and night (Tmin) in the mid-infrared and thermal infrared portions of the spectrum. A vegetation index can be calculated from the visible and near infrared sensors to identify vegetation and estimate the 'greenness' or health of foliage. Global AVHRR imagery records are available at least four times per day. AVHRR data are thus useful for studies that require repetitive, regional scale analysis of climate, vegetation and environmental change (Huh 1991). By use of day-night surface temperature difference (dT) images, it is possible to define moisture domains in agricultural areas because water buffers the amplitude of the diurnal fluctuation of surface temperatures (Shih & Chen 1987). The frequent clear skies and dry atmospheric conditions of Egypt favor radiometric surface temperature measurements by remote sensing.

Patterns in the Nile delta were identified in a classification of Tmax, Tmin and dT images of 16 Aug 90 that reflected the classic *S. mansoni* prevalence maps described by Scott in 1935 (Malone et al. 1992); a transition zone of high dT values was seen in the southwestern delta that generally conformed to the outline of Scott's low *S. mansoni* prevalence region (Scott 1937). The broad thermal domains seen in the 16 Aug 90 image were seasonally stable in 18 Oct 90 and 14 Feb 91 dT images, suggesting that permanent features, not vegetation or climate, were responsible for patterns seen.

Detailed analysis was done on dT AVHRR images of 16 Aug 90 and 14 Feb 91 to further study the relationship of regional thermal domains to historical *S. mansoni* and *S. haematobium* distribution in the Nile delta (Malone et al. 1994). In both dT images, a series of transect profiles revealed a decrease in dT values of approximately 2°C at points approximating Scott's transition from low to high prevalence of *S. mansoni*.

Median dT values were then calculated for a 5 X 5 pixel area (28 km^2) centered on the latitude and longitude of 41 rural survey sites named in 1935, 1983 and 1990 surveys (Scott 1937, Cline et al. 1989, Michelson et al. 1993). For both 16 Aug 90 and 14 Feb 91, there was a significant inverse association between median dT values and *S. mansoni* prevalence in 1935 and 1983, suggesting that lower dT values reflect wetter hydrologic regimes that are more suitable for *S. mansoni*. A consistent trend was observed between dT and prevalence in 1990, but these values were not significantly correlated. Similar analysis for *S. haematobium* revealed a positive relationship of 16 Aug 90 and 14 Feb 91 dT and prevalence in 1935.

To substantiate regional environmental influences on current infection risk, *S. mansoni* prevalence data from the Nile delta surveys of 1983 and 1990 were compared with the rank order of Scott's 1935 data for 41 sites. Spearman rank correlation coefficients revealed a significant relationship between 1935 and 1983 data and between 1990 and 1935 data. By 1983, extension of *S. mansoni* into formerly low prevalence zones of the southwestern delta was observed as well as a dramatic decrease in the prevalence of *S. haematobium;* this trend was maintained at the time of the 1990 survey, when a diminished prevalence of both *S. mansoni* and *S. haematobium* was observed. *S. haematobium* prevalence in 1935 diminished as *S. mansoni* prevalence increased; no correlation was found between the ranked 1935 prevalence data and the greatly decreased *S. haematobium* prevalence rates of 1983 and 1990. Results indicate that AVHRR thermal-moisture domains represent stable environmental features in the Nile delta that reflect historical risk of *S. mansoni* on a regional scale and suggest that these features continue to influence moisture regime and *S. mansoni* risk 55 years after Scott's 1935 survey in spite of delta structural changes and hydrologic consequences of the Aswan High Dam. In Florida studies on citrus freeze damage, stable terrestrial thermal patterns observed by GOES climate satellites were found to be generally governed by broad soil types, soil depths, soil drainage classes, surface vegetation and land use (Shih & Chen 1987). Moisture domains seen in the 16 Aug 90 and 14 Feb 91 AVHRR images may reflect water retention characteristics related to underlying geologic formations, the texture and depth of the agricultural soil layer or elevation above sea level.

Bulinus truncatus, the *S. haematobium* intermediate host, is able to tolerate several months of drought and high temperatures in its biotope. *Biomphalaria alexandrina*, the snail host of *S. mansoni*, is more sensitive to extreme temperature variations and does not survive seasonal drought well; it tends to be found in slowly moving waters of shallow drains in irrigation networks where it may be more sensitive to drought periods, annual irrigation system closure and dryness between irrigation cycles (Abdel-Wahab 1982).

Additional work is needed to elucidate factors underlying regional thermal domains and the possibility that similar thermal domain associations can be found at local community scales in the Nile delta. This can be addressed in future studies by developing geographic information system (GIS) models that include higher resolution Landsat TM imagery, detailed agricultural and climatic databases, snail population distribution maps and accurate data on infection prevalence. A successful environment-based GIS for schistosomiasis in Egypt can provide a vehicle for later incorporation of community based sociologic and prevalence data and maps of water contact, water supply and sewage disposal as they affect control management at the local level.

FASCIOLIASIS

The unique biology and life cycle strategy of *Fasciola hepatica* make it amenable to effective use of GIS control models in several respects:

Climate Sensitivity - The high environmental sensitivity and focal nature of *F. hepatica* transmission typically results in wide variation in infection prevalence in animals in fluke enzootic regions. Explosive outbreaks of fatal disease due to fascioliasis were documented in sheep in Europe as early as the 18th century. In cattle, a 100-fold difference in parasite burdens can occur between years owing to the effect of climate variation alone on snail host populations, intramolluscan asexual multiplication, survival of fluke eggs and persistence of metacercariae on pastures. Climate forecast models for fascioliasis, originally developed for use in Europe, have been adapted for use the United States, Australia and elsewhere to advise stockmen on the relative need for flukicide treatment each year. In the southern United States it has also been possible, using a forecast model and 30-year average climate records, to develop a profile on the seasonal pattern of transmission, relative severity and range of fascioliasis in divergent climate zones of that region (Malone & Zukowski 1992).

Climate risk data can be included in a GIS as separate layers on long-term climate patterns (eg. 30-year-average data), maps of annual values or even as surrogates of climate. In unique work in Africa, the distribution of TseTse vectors of trypanosomiasis and tick vectors of East Coast Fever (*Theileria*) were successfully characterized by supplementing long-term climate average records with monthly vegetation index values derived from NOAA environmental satellite imagery. Vegetation index was strongly correlated with long term average rainfall values and saturation deficit (humidity) and with important biological variables of vector populations, such as population density, mortality rate and size (Rogers & Randolph 1993).

Vector Habitat Nidality - Climate forecasts provide a comparison of annual variation in *Fasciola* transmission on a *regional* scale, but no provision is made for potential infection pressure related to the amount of snail host habitat present on specific premises grazed. The differential suitability of pastures for lymnaeid snail habitat can result, like climate variation, in a 100-fold variation in infection prevalence between individual cattle operations in a given agroclimatic zone (Malone et al. 1992). As compared to more ephemeral vectors such as mosquitoes, snails tend to be present year after year in the same habitats and population generation times are relatively long. Stocking rate and the proportion of a farm occupied by habitat have been considered to be the two most important factors influencing cost benefit of control of fascioliasis in sheep in Australia (Meek & Morris 1981). A similar relationship has been described between snail habitat extent and prevalence of human schistosomiasis in Iran (Rosenfield 1987).

Soil-hydrology GIS models for estimating farm-specific risk of fascioliasis in cattle have been developed for use in the Chenier Plain (Zukowski et al. 1992) and Red River basin (Malone et al. 1992) ecologic zones of Louisiana. Image overlays of soil type maps, hydrologic features shown in 7.5' United States Geologic Survey quadrangle maps and farm boundaries were compared to snail habitat maps or herd egg shedding prevalence. Farm boundaries were derived from aerial photographs or pasture vegetation seen in a post-harvest Landsat MSS satellite infrared image. Fluke egg shedding indices (mean number of eggs per 2 g of feces in 12-15 random samples per herd X prevalence %) were placed in rank order and iteratively fit to soil-hydrology parameters by regression analysis. The egg shedding index is an expression of egg abundance.

In the Red River basin, soil types ranged from sandy loams to hydric clays. The rank of herd egg shedding indices regressed significantly against a snail habitat risk factor derived from the proportion of soils present, slope and the length of interfaces of pastures with water bodies and other major hydrologic features. In the chenier plain region, the ranked egg shedding indices correlated with the area of Hackberry-Mermentau soils on cheniers (relict beaches), associated Mermentau soils and the length of chenier-marsh interfaces. A general association of *Fasciola* and certain soils has also been reported in Wales (Wright & Swire 1984). Japanese workers associated soil type with prevalence of *S. japonicum* (Nihei et al. 1981). Such wide variation in site-specific snail habitat risk must be considered, with climate data, in GIS models aimed at making treatment and control decisions for fascioliasis. GIS models based on environmental features can be expected to be extrapolated with validity only within the same ecologic zone; different factors or different weighting of data may be required to adapt risk indices to other scenarios, such as the altiplano of Bolivia or the southern Caspian region.

Control of Livestock Populations - Livestock are ordinarily confined in herds or flocks of known number in specific grazing areas. Even in unfenced areas, producers can often identify areas used by animals under their control (Sollod & Stem 1991). This facilitates effective treatment programs and makes it possible to estimate relative risk of fascioliasis in a given grazing area by infection prevalence in resident animal populations. For zoonotic fascioliasis, pasture and range boundaries could be defined in a GIS, with livestock prevalence data, and used: (1) to plan and monitor control based on reducing fecal egg contamination of snail habitats by animal populations and (2) to identify high risk areas for watercress and other vegetation used for human consumption.

Potential Integration of Geographic, Mathematical and Cost-benefit Analysis Models - Adoption of a geographic approach by GIS can provide the environmental context for fascioliasis and a systematic way to evaluate variation in parasite distribution on both a broad scale and a local scale. GIS results can then be used with mathematical models that suggest and compare control strategies on given premises based on intrinsic life cycle reproduction and mortality rates of *F. hepatica*. Mathematical models are relevant, like the parasite population described, in the context of a given environment.

Preventive treatment of livestock populations is realistic only if treatment is of recognized cost-benefit to producers. An appropriate approach in cost-benefit analysis is to identify a target economic threshold of infection below which morbidity or production losses do not occur and then monitor success based on that criterion. This is currently a weak link for practical control models: (1) there is limited data on economic thresholds for fascioliasis in cattle; (2) monitoring infection levels in control programs is dependent primarily on unprecise fecal sedimentation egg count data and (3) the same level of parasitism can have dramatically different effects on animal production depending on nutritional state and animal husbandry practices.

Computer expert systems can store and process large quantities of complex data that enhance the ability of the mind to make sound judgements and they allow transfer of evaluation criteria to the novice that were gained by years of field experience. Available information suggests that geographic models can be developed, using GIS, that can be integrated with site-specific mathematical models and cost-benefit analysis components to construct comprehensive decision-making systems. Computer systems needed, including complete image analysis and GIS capabilities, are now available for use at the microcomputer level at reasonable costs of less than $25,000.

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