Original Article

Spatial Analysis and Remote Sensing for Monitoring Systems of *Oncomelania nosophora* Following the Eradication of Schistosomiasis Japonica in Yamanashi Prefecture, Japan

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**SUMMARY**: In order to develop an inexpensive, simple, and accurate method of monitoring for the reemergence of schistosomiasis japonica in Yamanashi Prefecture, Japan, the distribution and habitation density of the intermediate host, *Oncomelania nosophora*, were spatially analyzed using geographic information systems. The 1967-1968 density distribution maps prepared by Yamanashi Prefecture and Nihei were digitized and geocoded. The habitats and population density of *O. nosophora* were estimated by referring to the data compiled by the Yamanashi Association for Schistosomiasis Control (1977). These earlier findings were compared with average population densities between 1996 and 2000 previously recorded (Nihei, N., Kajihara, N., Kirinoki, M., et al., Parasitol. Int., 52, 395-401, 2003 and Nihei, N., Kajihara, N., Kirinoki, M., et al., Parasitol. Int., 53, 199-205, 2004). A variance map was created to compare the spatial distribution maps of population density from each of the two periods of interest. The changes in distribution were remarkable and the map was found to be effective for future control. The most appropriate monitoring sites were chosen on the basis of the spatial population density maps and the variance map. Moreover, the paddy fields at risk were extracted using the normalized difference vegetation index value based on Advanced Land Observation Satellite images. The combination of this method with the global positioning system provides an inexpensive means of monitoring modern schistosomiasis endemic areas in Japan and also in China, the Philippines, and other countries as well, where the intermediate snail grows in paddy fields and marshlands under consistently wet conditions.

**INTRODUCTION**

The epidemic of schistosomiasis japonica in Yamanashi Prefecture was officially declared to have ended in 1996, thus completing the national eradication of this endemic disease. However, populations of the intermediate snail host, namely, *Oncomelania nosophora*, still exist. Hence, fixed-point observations recorded using geographic information systems (GIS) from 1996 to 2000 were compared with the results of fixed-point observations recorded using geographic information systems (GIS) from 1996 to 2000 (11,12). Furthermore, areas supportive of *O. nosophora* habitation were represented diagrammatically following analyses of aerial photographs and field surveys. The trends in habitat range and density were studied, enabling the identification of areas that still need to be continuously monitored. Snails were collected several times each year, and specimens were examined to identify any cases of infection. If the schistosomiasis had indeed reemerged, the condition of the snails could be immediately assessed. Here, we established a precise, efficient, inexpensive, and rapid method of monitoring the risk of future outbreaks of schistosomiasis japonica derived from imported cases. It has been claimed that remote sensing and GIS have been actively adopted to monitor for outbreaks of schistosomiasis japonica by considering factors such as climate change, changes in land condition, and migration of patients in China and the Philippines (13,14). However, with few exceptions, there have been very few reports on the use of these techniques (15-22). The results of the present observations could be used as a reference for monitoring the risk of schistosomiasis japonica in countries other than Japan.

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MATERIALS AND METHODS

Data: (i) Data from YIPH (1967-1968): O. nosophora density distribution map by Nihei (no original map; extant map hand-drawn due to the lack of photocopying facilities at a scale of 1:50,000 on topographic maps issued by the Geographical Survey Institute). (ii) 1970 statistical data for average O. nosophora habitat density per municipality based on data from YASC (1977) (5). (iii) 1996-2000: Data on O. nosophora population density per fixed point calculated based on the results of a survey conducted in Yamanashi Prefecture from 1996 to 2003 (12). (iv) Digital map of Yamanashi Prefecture at a scale of 1:25,000 (PFM; Pasco Co., Tokyo, Japan). (v) Aerial photos on a scale of approximately 1:20,000 (taken by the Japan Forestry Association, Tokyo, Japan in 2002). (vi) Two advanced land observing satellite (ALOS) images taken in April and August 2007 (JAXA, Tokyo, Japan). (vii) Data from the following GIS software: ArcGIS 9.1 + Spatial Analyst Extension (ESRI, Redlands, Calif., USA).

Density distribution map of O. nosophora created on the basis of surveys conducted in 1967-1968: The Yamanashi Prefecture authorities had conducted a detailed survey of the density of snails in each habitat in each municipality for 2 years. The distribution in the habitat was estimated as the density of O. nosophora populations per square meter (m²) by dividing the habitat into 3 categories, namely, <10 snails/m² (low), 10-19 snails/m² (medium), and ≥20 snails/m² (high) each year, from which the density distribution map was created. The coordinates were then added, and the resulting data was scanned. The snails mainly inhabited paddy fields and associated irrigation channels; hence, habitat density is represented as a linear, and not an aerial value. The coded density data for the established 3 categories were joined for 2 years per code, and a GIS layer was subsequently created. When the maps were overlaid and the lines were duplicated, the higher numeric value was selected, and a density distribution map was created by defining 0.5 m as the line buffer (hereafter referred to as the “1967-1968 GIS density distribution map”).

Estimation of the average density of O. nosophora per municipality and supplementary data for 1967-1968: In order to prepare statistical data on the snail population density, density was divided into 3 categories that could be depicted in the maps. Accordingly, the municipality map was overlaid with the 1967-1968 GIS density distribution map. To enable aggregation of the linear data per municipality, the 3 categories of habitat density (i.e., “high,” “medium,” and “low”) were defined in 2 ways: (a) 20, 10, and 1/m² and (b) 25, 15, and 5/m², following the general method of presuming a numerical value. The snail density per municipality and the total populations were calculated (GIS density). The calculation of density from the GIS supplementary data was performed using “(a),” since these values were obtained when the GIS density and the existing data were compared. A supplementary GIS habitat density map was then created on the basis of regression line.

Creation of a spatial density distribution map for O. nosophora for 1967-1968: The O. nosophora habitat extended to paddy fields and fallow farmlands from irrigation channels during the rice cultivation period, and from spring to autumn. Considering such expansion, a GIS spatial density distribution map was created by the addition of supplementary data from the search ranges of 100 m, 250 m, and 500 m on ArcGIS using the supplementary GIS habitat density map. An isopleth map of O. nosophora density was created by superimposing the density isopleths onto this map.

Creation of a density distribution map for O. nosophora for 1996-2000: Snail habitat observations were conducted at 120 fixed points from 1996 to 2000, but due to budgetary constraints, the number of fixed points was reduced to 60 between the years of 2001 to 2003. For the present study, we used the average populations for the first 5 years, when a higher number of fixed points were used. The number of specimens collected was kept consistent within a 0.25 × 0.25-m frame at 2 water inlets per point. In order to compare these data with those of the 1967-1968 GIS density distribution map, the averages were converted to equivalents collected per square meter. The density distribution map per fixed point was displayed by classifying the data into 5 categories. Using these fixed points, we created a GIS spatial density distribution map of the snail population for the period from 1996 to 2000 within a 250-m search area.

Creation of a spatial density variance map of O. nosophora between 1967-1968 and 1996-2000: GIS software, Arc View, was used for dividing and displaying the density of each habitat of Oncomelania in 1967-1968. The habitat density at the investigated fixed points from 1996 to 2000 was similarly divided and displayed as classes of 100. The values from the spatial distribution map of 1967-1968 were deducted from those of the 1996-2000 map (green denotes positive values, white denotes no change, and red denotes negative values). As regards the range categories for habitat density at the 120 fixed points, maps were created ranging from 50 to ±50.

Determination of the range of paddy fields with possible O. nosophora habitation bases on ALOS image data from April and August 2007: The land surrounding O. nosophora habitats in the Kofu Basin consist of paddy fields, fallow lands, orchards, and other types of land. In order to determine the range of paddy fields and fallow lands with possible O. nosophora habitation, the normalized difference vegetation index (NDVI) was computed using a near-infrared band and a visible-light red band of 2 ALOS images taken in April and in August of 2007 (23). This index represents the existence and degree of vegetative activity, and shows the value normalized by –1 to 1. We set the threshold value of the NDVI to determine the area of flat land lacking vegetative cover, and we visually deciphered the ALOS images that had been taken in April. We then calculated the threshold value for determining the area of land with extensive rice cultivation and tracts of land with thick vegetation using the ALOS image data that had been obtained in August. Furthermore, two areas were overlaid, namely, the area of flat land ranging from –0.36 to –0.22 of the threshold value of the NDVI of the image data in April, and the area of green tracts of land with a threshold value of 0.28 or more of the NDVI in August. The area of flat land on the image obtained in April that appeared as a tract of land with thick vegetation in the image obtained in August was determined to be the area used for paddy cultivation.

RESULTS

Estimation and spatial analysis of the population density of O. nosophora in Yamanashi Prefecture in 1967-1968: The 1967-1968 O. nosophora digital density distribution map of each municipality shows that the population densities of the snails differed significantly according to type of land examined (Fig. 1). Snail habitats were found not only
The snail population were determined to be 0 - 35 snails/m² in 18 municipalities on the basis of the existing data; the differences between values observed in different municipalities were significant. The smaller range per municipality was used to estimate (a) small and (b) large types of population (1 - 13 snails/m² in the former case, and 5 - 17 snails/m² in the latter). The graph in Fig. 2 shows a comparison between the average density corrected by GIS and the average density based on the existing data (Table 1; GIS supplementary average density). Since the data in this figure demonstrate a close correlation, the expression y = 0.519x + 1.315 (line a), was used to for the data correction. The corrected value was calculated with the correlation coefficient, save for (H) and (K) points of the exception value from all endemic village data points (line b). The smaller estimates were closer to the existing data (3). Hence, the map for the estimated snail populations was created using line widths of 1 m and the density code categories of 20, 10, and 1 snails/m².

Expansion of the snail habitat during 1967 - 1968 was expected during the wet stage of paddy rice cultivation. In order to estimate the spatial distribution of the O. nosophora population, the GIS spatial distribution maps were created with search areas at 500 m, 250 m, and 100 m from the density line (Figures are omitted). A search area of 500 m was considered appropriate for the spatial analysis in order to accurately represent O. nosophora population distribution, including that in low-density areas. However, this approach produced some false positives, implying that even in 1967 - 1968, the snail populations were unlikely to inhabit areas such as hilly terrain, uplands, and the upper reaches of alluvial fans. Our experience suggests that a map with a search area of 250 m could be used to adequately approximate the distribution status, while at the same time highlight the high-density areas relatively well. In general, it would not have been easy to identify high-density habitats using a map with a buffer area of 100 m, because using this approach, the distribution area would be less than the actual area.
The more accurate estimation of the snail habitat spatial density distribution was compared to the current fixed-point observation results. In order to apply the data to future field surveys, an isoline of the density, namely, 1 specimen/m², was prepared for the 1967-1968 density distribution map (Fig. 3A). To this end, a density distribution map with a buffer area of 500 m was created as the background, part of which was magnified (Fig. 3B). The isoline shape of the Kofu Basin resembles the density distribution map for a search area of 500 m. It was easy to identify areas on the map with a population density ranging from high to low, without relying on color separation. When this map was overlaid on the map with a buffer area of 500 m, the snail population distribution was estimated on the basis of the high-density areas, and population status could be accurately identified. Once this map was expanded, it could be used for field surveys. The areas lacking a snail habitation were indicated as shch on the map.

Changes in the spatial density distribution of *O. nosophora* between 1967-1968 and 1996-2000: Fixed points for the spatial density distribution map for 1996-2000 were not specified in Kofu City, nor in other areas to the east (Fig. 4). This was because there were no habitats for *O. nosophora* due to advanced urbanization, which had brought about changes in the use of surrounding paddy fields and orchards. *O. nosophora* no longer inhabits the center of the Kofu Basin. In the western part of the Kofu Basin, high-density snail populations were observed in areas with paddy fields and orchards situated in complicated topographic terrains and alluvial fans (8). On the basis of these fixed points, we applied a buffer area of 250 m (Fig. 4) and created a map similar to that created for 1967-1968 (Fig. 5). A variance map was created by overlaying the 2 data periods (Fig. 6). The areas that required monitoring were magnified and were overlaid with the fixed-point distribution map for 1996-2000 (Fig. 7). Figures 6 and 7 display the density difference per area observed for each period with respect to gradation. In the western region, at the confluence of the Midai and Kamanashi Rivers, the *O. nosophora* habitat was large and the population density was high as well. Although this habitat had decreased in area between the years 1996 to 2000, high-density areas were nonetheless observed. On the variance map, high-density snail populations were observed in the western section during both periods, although the higher value was observed in more recent years, i.e., the study revealed the presence of a high-density snail population during the period 1996-2000 (green). Areas on the map that did not undergo any change in the snail population density for 40 years were represented in white. There are currently few habitats at the center of the Kofu Basin, the central region of which is colored pink. At present, urbanization has precluded snail habitation in some of these areas, although there remain some paddy fields in which this type of snail can survive. A clearly delineated boundary was observed between the green and pink zones on the map. The pink area, i.e., the northern portion of the Midai River, sug-
gests a particular pattern of change, as this area used to be a high-density habitat, and has since been converted into an industrial complex.

**Determination of areas at risk using NDVI values from the ALOS image data**: Possible *O. nosophora* habitation areas, i.e., areas at risk, were also identified as determined based on aerial photographs (11). When the isodensity map for 1967-1968 was superimposed onto these aerial photographs, the high-density snail habitation areas were more clearly visible. When the paddy fields and areas of fallow land, i.e., those areas that had been clearly identified as suitable habitats for snail populations, were examined using the NDVI data of the 2 ALOS images taken in 2007 (Fig. 8), the need to survey the paddy fields in risk areas became evident.

**DISCUSSION**

GIS can be a rather useful tool for analyzing the distribution and population density of the intermediate host of schistosomiasis japonica, as well as for identifying spatial changes in the distribution of this host. All figures generated for this study were geo-coordinated, thus enabling the overlay of global positioning system (GPS) monitoring data (11). A high-quality, yet simple and inexpensive monitoring system was thus established on the basis of data acquired by mobile
Monitoring paddy fields in risk area in Yamanashi Prefecture using the NDVI data of the 2 ALOS images taken in 2007. Paddy fields are areas of −0.36 to −0.22 of the threshold value of the NDVI of ALOS image data in April, and the area of green tract of land with a threshold value of 0.28 or more of the NDVI in August. **Fig. 8.**

Results of snail monitoring survey using camera with GPS on detail aerial photographs and population isoline map around the habitats of *O. nasophora* in Yamanashi Prefecture, Japan. **Fig. 7.**

GIS (12). Digital density distribution maps composed of 3 population density layers (“high,” “medium,” and “low”) enabled the visualization of distinct areas identified as having different population density ranks. The population density per square meter (m²) value, which is the standard index, was estimated based on the results of population surveys conducted during different years and by using different survey methods applied in the Kofu Basin in Yamanashi Prefecture. Recently, the importance of GIS in the fields of parasitology and tropical medicine has been emphasized in countries other than Japan. However, to date, the few studies that have been conducted have only involved the visualization of data and the analysis of distribution elements via overlay with other factors. The present case study demonstrates that GIS technology in Japan can be effectively used for related future studies.

Emergency measures for quickly dealing with a variety of problems have been developed by techniques involving the overlay of a digital map detailing *O. nasophora* distribution (indicative of the schistosomiasis japonica risk) and national spatial data that include population migration. This helps guarantee the safety of local citizens concerned about such risks. Furthermore, such an approach can be used for eradication measures that take the environment into consideration, and the addresses demands for appropriate surveys and monitoring. Such a monitoring system should be established in the future, as eradication measures based on variations in the geographical distribution of *O. nasophora* have long been considered essential. Such eradication measures were initially delayed in Japan due to the confusion prevalent during the post-World War II period. Once the snail habitat range reached its peak, a distribution map was created to provide data for the concretization of irrigation channels, to gain a better understanding of the current status of the host, and to generate measures for *O. nasophora* eradication. Prior to the emergence of the current GIS technology, different types of maps and data had been prepared, and these previous sources were used in the present GIS analysis. Researchers at the YIPH and Nihei in the 1960s created maps relying primarily on their expertise in cartography at a time when maps on a scale of 1:25,000 of the complete habitat range for *O. nasophora* were unavailable.

A spatial density map was created here for the entire Kofu Basin. In order to compare this map with the distribution maps that had been drafted in the past, numerical data was necessary. Accordingly, a GIS analysis was conducted using the available data on the population densities in each municipality, other estimates (statistical data), and the geographical data supplemented by preexisting distribution maps; the calculated data were confirmed to be consistent with the statistical data.

For the 1996 - 2003 population survey (11, 12), fixed-point observations were conducted using GPS accurate to within 50 cm; these previous results not only contributed to the findings of the present analysis, they are expected to remain useful for future reference.

The map of density differences highlighted any possible spatial and numerical discrepancies with respect to the findings of conventional ecological science. This map was used to compare quality requirements between the 2 maps (Figs. 4...
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REFERENCES


