

The Distribution of *Biomphalaria* spp. in Different Habitats in Relation to Physical, Biological, Water Contact and Cognitive Factors in a Rural Area in Minas Gerais, Brazil

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A total of 256 sites in 11 habitats were surveyed for Biomphalaria in Melquiades rural area (State of Minas Gerais) in August and November 1999 and in March 2000. Of the 1,780 Biomphalaria collected, 1,721 (96.7%) were B. glabrata and 59 (3.3%) B. straminea. Snails were found in all habitats except in wells, with the largest mean numbers in tanks, seepage ponds and canals, and the smallest numbers in springs, rice fields and fishponds.

People's knowledge of the occurrence of Biomphalaria at the collection sites and the presence of Biomphalaria ova were strongly correlated with the occurrence of snails, and distance between houses and collection sites, as well as water velocity were inversely correlated with Biomphalaria occurrence ($p < 0.001$). The strongest predictor of Biomphalaria occurrence was the presence of tilapia fish in fishponds. Fourteen Biomphalaria (0.8% of all snails) found at 6 sites were infected with Schistosoma mansoni. Suggestions are made for the utilization of local people's knowledge in snail surveys and further studies are recommended on the possible use of tilapia for biological control of Biomphalaria in fishponds, as well as modeling of S. mansoni transmission and reinfection.

Key words: *Biomphalaria glabrata* - *Biomphalaria straminea* - geographic distribution - environmental factors - local knowledge - Minas Gerais - Brazil

In view of the wide range of natural and man-made snail habitats in Brazil that are used by humans for domestic, recreational and occupational purposes, it is essential that the distribution of schistosomiasis intermediate hosts be known for the design, implementation and evaluation of con-

trol programs. Pessoa and Martins (1988) reviewed the literature on the distribution and ecology of *Biomphalaria* species in Brazil in relation to habitat and noted that this genus has a great capacity to adapt to different environmental conditions. Schmelzer et al. (1997) found *B. straminea* to be widespread in lakes in Fortaleza city. In small irrigation canals in gardens in Salvador city, *B. glabrata* was the dominant species (Coutinho 1950).

Seven of the 10 species of *Biomphalaria* endemic in Brazil occur in Minas Gerais. *B. glabrata* is the most widespread species, occurring in 257 of the State's 853 municipalities, followed by *B. straminea* (10.4%) and *B. tenagophila* (4.1%) (Souza et al. 1997, Souza & Lima 1997a,b). *B. glabrata* inhabits mostly small tributary streams in the northeastern part of that State (Freitas 1968). In Belo Horizonte municipality, more streams harbored

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aquatic snails than any other habitat but irrigation canals yielded the largest number of *B. glabrata*, followed by streams, swamps, drainage canals and ponds, in that order. A number of other investigators pointed out the importance of canals as a habitat of *Biomphalaria* and transmission site (Pessoa & Martins 1988).

Past malacological surveys in Brazil failed to study two snail habitats in detail: household water tanks and "bicas" (traditional household water conduits). Household water tanks, including both the older cement tanks on the ground and the newer asbestos and plastic tanks on top of houses, are used for all types of domestic uses, and the cement tanks for cattle watering as well. Most of them being supplied with stream or spring water, they confer considerable risk of schistosomiasis exposure.

Bicas channel canal, stream or spring water via bamboo or (more recently) plastic pipes continue to be used in many rural communities in Brazil either as the primary or as a secondary source of household water. All water-related household activities, including washing dishes and clothes, as well as bathing, are carried out at these sites, with domestic and bathing activities often carried out at different bicas.

Fishponds, increasingly constructed in Brazil and other countries in the tropics for the purpose of supplying protein to increasing populations, have been identified as another potential source of schistosomiasis infection, especially if they are not properly maintained (Editorial 1970, Ferguson & Ruiz-Tieben 1971). A field trial by Azevedo (1960) in a Brazilian lake indicated that *Tilapia melanopleura* is a predator of *B. glabrata*, which was confirmed in the laboratory by Andrade and Antunes (1969). In Bahia, the local fish *apiaiar* (*Anthrónatus ocelatus*) was used for snail control (Naftale Katz, pers. commun.). Several other fish species have been found to be effective predators of snail intermediate hosts, and recently *T. rendalli* and the chichlid *Sargochromis codringtoni* have been used in schistosomiasis control in fish ponds in Zimbabwe (Chimbari et al. 1999).

A potential source of information on snail distribution, local people's knowledge, has seldom been considered in malacological surveys, which are normally designed by urban-based scientists using preconceived ideas of snail distribution. If local people have reliable information about the occurrence of *Biomphalaria* they may then become instrumental in working with control teams, in identifying snail habitats and thus schistosome transmission sites. Such local involvement is in agreement with the primary health care approach in schistosomiasis control advocated by the World Health Organization (1990).

Spatial studies of intermediate host snail distribution using computer-based GIS technology have been carried out during recent years for locational accuracy and interactive analysis of results in Brazil (Bavia et al. 1995), Egypt (Malone et al. 1994) and China (Spear et al. 1996). At the community level, the use of DGPS (differential global positioning systems) permitted the preparation of vector maps in rural areas lacking topographic maps (Hightower et al. 1998).

The purpose of this study is to examine the distribution of *Biomphalaria* in all types of natural and man-made habitats found in the rural area of Melquiades in Governador Valadares Prefecture in the State of Minas Gerais. This study forms part of an epidemiological study of *Schistosoma mansoni* in Melquiades, which included the administration of mass chemotherapy to the population in 1998/1999 (Bethony et al. 2000).

STUDY AREA

Melquiades is a 100 km²/50 km west of Governador Valadares city. The Melquiades population of 1,200 lives in 14 hamlets in 12 river valleys, depending on subsistence agriculture involving the growing of corn, beans and rice and raising cattle and commercially grown bananas and dairy products. The study area varies in elevation from 250 to over 900 m, providing considerable precipitation in the mountains and numerous fast-flowing perennial streams. The local population constructed canals for domestic uses, to irrigate rice fields and drain pastures in the stream floodplains. Bicas continue to be used by most households and some have shallow wells. A centralized piped water system with a deep well source was installed by a water utility company in four hamlets (Rua da Grota, Rua dos Bastos, Campo de Futebol, and Rua dos Marinho) in 1997 (Fig. 1). No snail control program has been carried out by the Ministry of Health in Melquiades.

METHODS

During exploratory snail surveys with the assistance of local farmers and fishermen in November 1998 and March 1999, 256 collection sites were identified. In this selection an attempt was made to include all major water contact sites of the 186 study households at nearby streams and canals and the cement tanks, as well as some of the tanks on roof tops and wells. All bicas and fishponds were included. Away from the hamlets representative streams, irrigation canals and drains, rice fields, swamps, and seepage ponds were sampled. All sites were sampled by the same collector (HK) in August (cool, dry season) and November 1999 (start of rainy season) and March 2000 (end of rains).

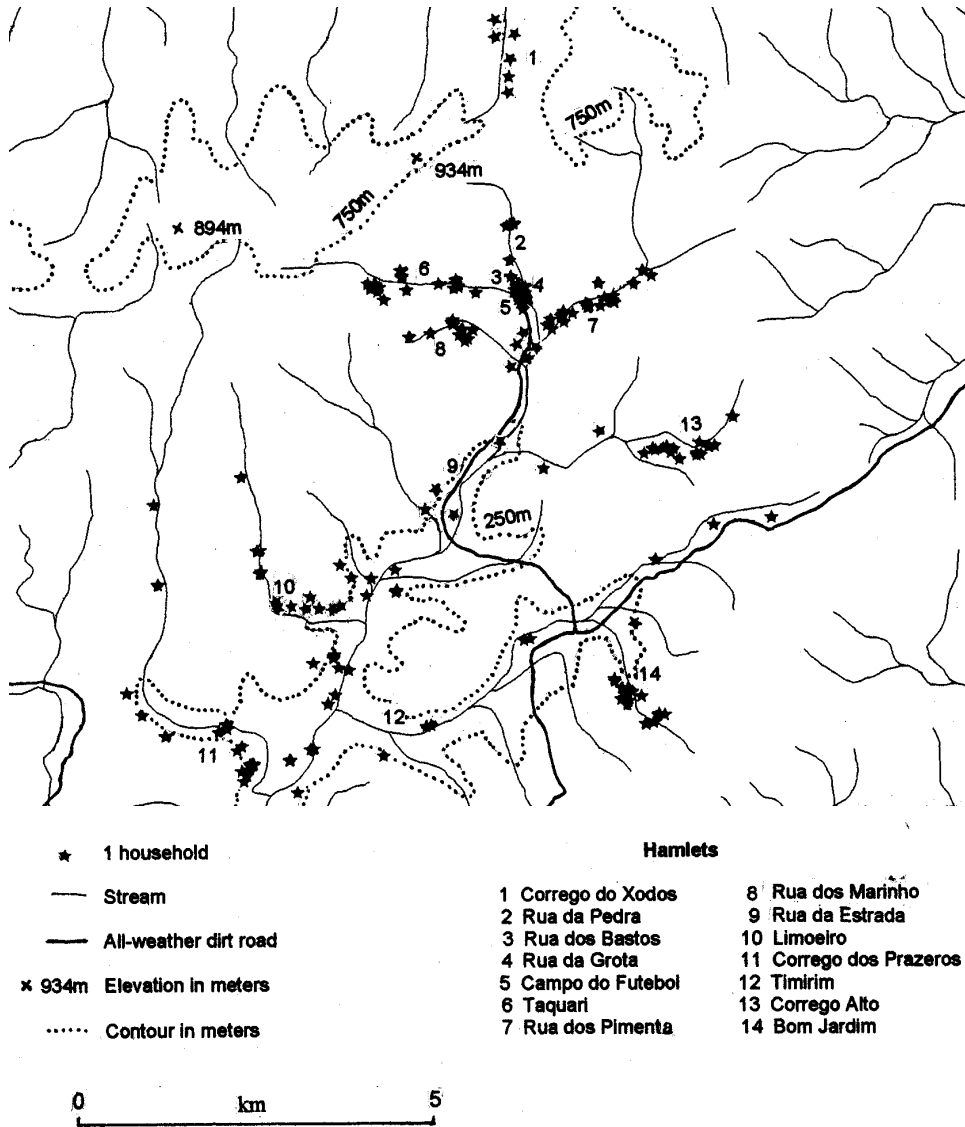


Fig. 1: Melquiades study area: households, hamlets, streams and topography

Each site was surveyed for 5 min using the standard Fiocruz metal scoop (Souza et al. 1997b) and occasionally forceps at rocky sites, on wooden planks and other sites or microhabitats inaccessible with the scoop. Information on number of snails and ova collected, type of habitat, distance to nearest house, whether the site was a water contact site, and physico-biotic characteristics (substrate, vegetation density, visible pollution, water velocity, presence of fish and ducks), and home owners' knowledge about the occurrence of *Biomphalaria* at the sampled sites on their compounds were recorded on forms at each site. *Biomphalaria* snails 3mm and larger in diameter

and ova were collected for identification and snails were measured and shed for cercaria at the Centro de Pesquisas René Rachou in Belo Horizonte and the Biomedical Research Institute in Rockville, USA.

A DGBS (Trimble AgGPS132) system and GIS (MapInfo) software were used to map all snail collection sites, houses and roads after superimposing all georeferenced points on a 1:100,000 scale map to show streams and contours.

RESULTS

General distribution - Of the 1,780 *Biomphalaria* collected, 1721 (96.7%) were *B. glabrata*

and 59 (3.3%) *B. stramina*. Also 252 *Physa* sp. and 65 *Drepanotrema* sp. were collected. *Biomphalaria* snails were recovered from all habitats except wells and from all 14 hamlets, although its spatial distribution varied considerably in some localities and habitats (Figs 1-7). Nearly one-third (30.1%) of the 1,780 *Biomphalaria* were collected in August, 858 (48.3%) in November and 386 (21.7%) in March. Similarly, 8 of the 24 *Biomphalaria* ova-positive sites were found in August, 14 in November, 8 in August and only 2 in March. The rains were late in November and had not flushed snails out of their habitats at the time of the survey but were heavy in March. Mean diameter of *Biomphalaria* in August was 6.8 mm, in November 9.1 mm and in March 8.0 mm. Twenty-two *B. glabrata*, found in 4 tilapia-free fish ponds, measured 18-26 mm, and the mean size of snails in ponds (12.4 mm) was larger than in any other habitat. Mean sizes were smallest in streams and canals. Mean diameter of the 56 *B. stramina* collected during the 3 surveys was 6.6 mm.

Fourteen *Biomphalaria* snails were infected with *S. mansoni*, 12 in August (2.2%) and 2 in March (0.5%) (Table I). Infected snails were found in 2 streams, one canal, one cattle tank and two bath bicas. Five of these 6 sites were located in the lowlands below or slightly above the 250 m contour, although most sites were between 250 and about 600 m (Figs 1, 2). The infected snails in March were collected from 1 of the bicas used for bathing by a visiting family not included in the study.

Using chi-square and bivariate Pearson correlation tests, statistically significant associations were noted between *Biomphalaria* snail presence and type of habitat, water velocity (inverse relationship), presence of fish (inverse) and *Biomphalaria* ova, pollution, distance (inverse) and people's knowledge of snail occurrence. No sig-

nificant associations were found with substrate, vegetation density, water contact site, pollution, and presence of ducks (Table II).

Distribution by habitat - At the habitat level, when using bivariate correlation tests, the variable most commonly and most strongly correlated with *Biomphalaria* presence was "seen *Biomphalaria* at site" in streams, fishponds and bicas. For tanks this variable was nearly significantly correlated ($P = 0.06$). Since both husbands and wives were interviewed and husbands were usually absent from the home during the day only 113 households could be interviewed about this question. The other variables significantly correlated with snail presence are discussed under their respective habitats below.

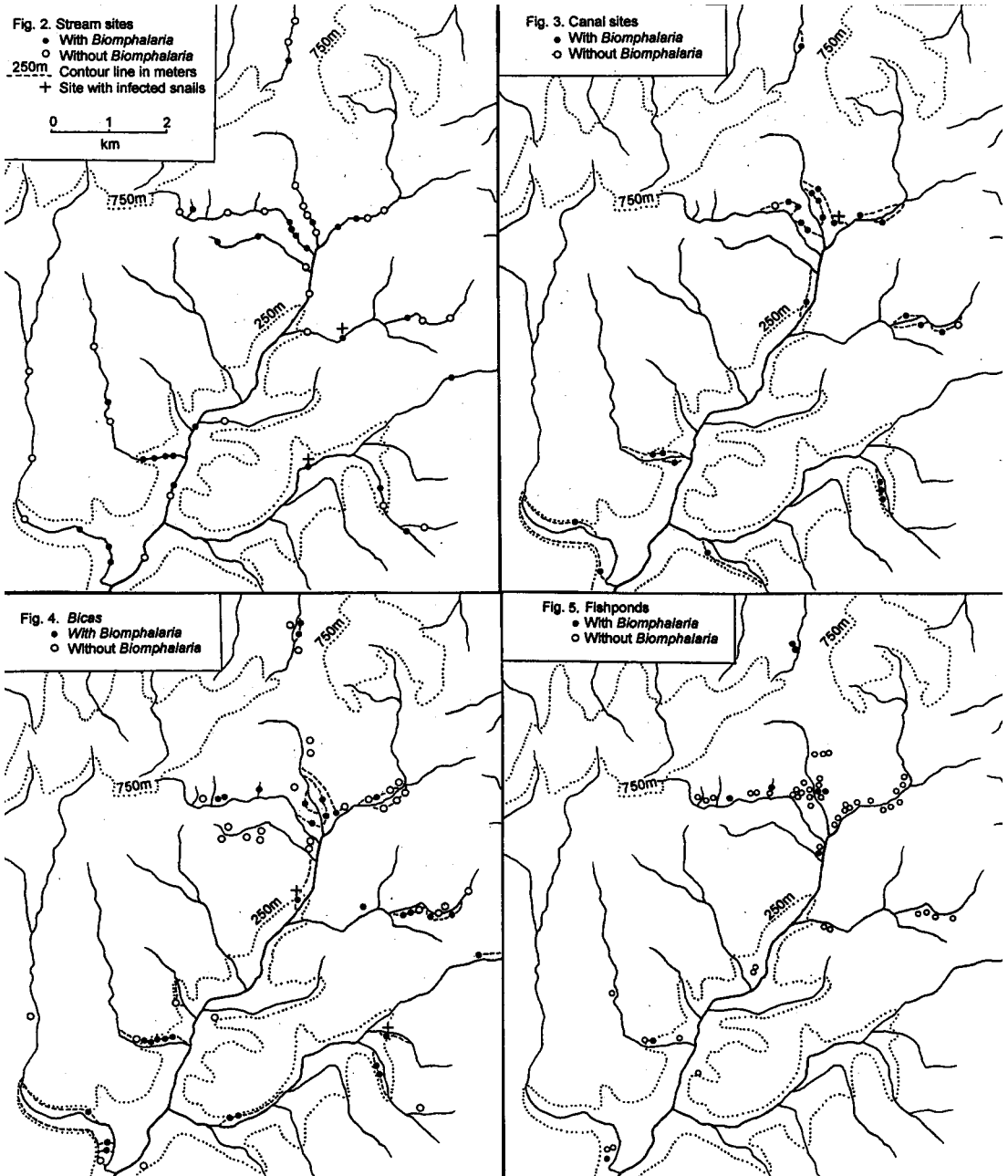
Streams - Streams had intermediate snail densities. *Biomphalaria* were most common in the lower portions of major tributary streams and rare in their fast-flowing headwaters. *B. glabrata* was present in 2 small streams in Taquari and Rua do Marinho just below *B. glabrata*-positive springs (Figs 2, 5). The small streams containing *Biomphalaria* in their upper reaches either were located in banana farms where banana leaves provided a suitable substrate (Córrego do Xódos, and Rua dos Marinho), or had dense semi-aquatic vegetation (Bom Jardim, and Taquari). In the environmentally variable stream environment the physical variables substrate, vegetation density and water velocity were the strongest predictors of snail presence (Figs 1, 2, Table III). During the rains in March, snail occurrence and density were particularly depressed in streams and none were found in the larger ones.

Springs - Springs at the heads of streams appear to be a major source of *Biomphalaria* for downstream sites where snails are washed out during the rains. Two of the 3 springs giving rise to

TABLE I
Number of *Biomphalaria* snails and ova by habitat and sites

Habitat	No. of snails	Mean no. per site	SD	No. of sites with ova (%)
Tanks (n = 16)	282	17.6	34.3	1 (6.3)
Seepage ponds (n = 2)	34	17.0	5.7	0
Canals (= 27)	419	15.5	14.7	6 (22.2)
Bicas (n = 62)	389	6.3	13.3	9 (14.5)
Streams (= 53)	324	6.0	9.8	3 (5.7)
Swamps (n = 5)	28	5.6	10.9	0
Drains (n = 9)	40	4.4	4.5	1 (11.1)
Fishponds (n = 62)	232	3.7	14.6	2 (3.2)
Rice fields (n = 4)	9	2.3	1.5	0
Springs (n = 11)	23	2.1	6.3	2 (18.1)
Wells (n = 5)	0	0	-	0

SD: standard deviation; n: no of sites



small streams in Taquari and Rua dos Marinho contained both *B. glabrata* snails and ova. The bica and a fishpond receiving the water from the third spring contained *B. glabrata* (Figs 1, 4, 5, 6). All dug, open springs around houses were free of snails but 2 bicas and a tank fed by springs via pipes contained *B. glabrata*.

Canals - All canals surveyed were diverted from streams but their flow was slower, their substrate

was mostly clay or organic material instead of the sandy and rocky substrate of streams, and they were thus more heavily vegetated than streams. Food rests from bicas and animal waste were major sources of organic material in canals, contributing to making them favorite snail habitats. Canals contained the largest proportion of *Biomphalaria*-positive sites (92.6%), and among the largest mean number of snails per site. They also had the largest

TABLE II
Distribution of *Biomphalaria* among 256 sites in relation to habitat, location, physical, biological,
and cognitive variables

Variables	Sites with snails	Sites without snails	Chi-square	P (2-sided test)
Habitat				
Stream	27	26		
Canal	25	2		
Fishpond	9	53	49.47	0.000
Bica	31	31		
Caixa	8	8		
Miscellaneous ^a	16	20		
Water velocity				
Standing water	22	79		
Slow (<10 cm/sec)	56	22		
Medium (10-30 cm/sec)	35	21	61.26	0.000
Fast (>30 cm/sec)	4	19		
Presence of fish				
No fish present	52	63		
Species other than tilapia	59	40	41.79	0.000
Tilapia	1	41		
Seen <i>Biomphalaria</i> at site ^b				
Yes	25	7		
No	18	63	30.41	0.000
<i>Biomphalaria</i> ova present				
Yes	22	2		
No	94	138	22.96	0.000
Distance (m)				
0-19	15	32		
20-49	46	65		
50-99	38	31	8.80	0.032
>99	17	12		
Substrate				
Sand/rocks	5	14		
Sand	19	23		
Cement	8	9	5.17	0.271
Clay/silt	80	84		
Organic	4	10		
Vegetation density				
No vegetation	45	61		
Sparse	36	48		
Medium-dense	28	22	2.88	0.411
Leaves or algae	7	9		
Water contact site				
Yes	91	120		
No	25	20	2.312	0.128
Pollution				
Not apparent	76	102		
Iron oxide	9	8		
Food rests	16	15	1.65	0.647
Human/animal feces/sewage	15	15		
Have ducks				
Yes	5	7		
No	111	133	0.068	0.795

a: includes 11 springs, 9 drainage canals, 5 wells, 5 swamps, 4 rice fields, and 2 seepage ponds; *b*: only 113 households could be interviewed.

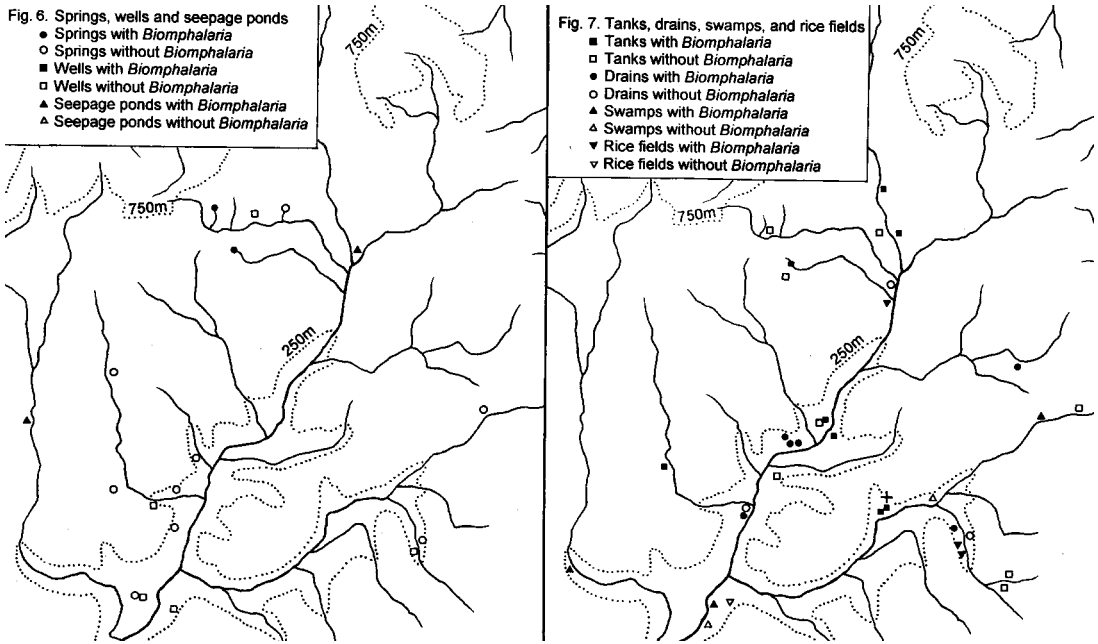


TABLE III

Distribution of *Biomphalaria* (presence or absence) among 256 sites in relation to location, physical, biological, distance, water contact and cognitive variables, by habitat

Habitat	Variables	Pearson correlation coefficient	Probability
Stream (n = 53) ^a	Substrate	0.349	0.010
Stream (n = 53)	Vegetation density	0.332	0.014
Stream (n = 53)	Water velocity	-0.593	0.028
Stream (n = 18)	Seen <i>Biomphalaria</i> snails at site	0.500	0.035
Fishpond (n = 62)	Presence of fish	-0.486	0.000
Fishpond (n = 34)	Seen <i>Biomphalaria</i> snails at site	0.504	0.002
Fishpond (n = 62)	Water contact site	0.311	0.014
Bica (n = 33)	Seen <i>Biomphalaria</i> snails at site	0.590	0.000
Bica (n = 62)	Presence of <i>Biomphalaria</i> ova	0.321	0.011
Bica (n = 62)	Distance ^b	-0.416	0.016
Bica (n = 62)	Pollution	0.249	0.051
Miscellaneous (n = 36)	Water velocity	0.408	0.007
Miscellaneous (n = 36)	Presence of <i>Biomphalaria</i> ova	0.354	0.037
Miscellaneous (n = 36)	Pollution	0.331	0.049

a: number of sites in brackets; b: distance from nearest house to snail collection site

proportion of sites with ova (22.2%) (Table I, Fig. 3). Few snails were found in canals that had been cleaned in March.

Bicas - Twenty-seven of the 33 (81.8%) bicas located on canals and 4 of 29 (13.8%) bicas fed by springs and streams, mostly at higher elevations, had *Biomphalaria*. Bicas receiving canal water tended to be located at lower elevations and thus received water more likely to be polluted with house-

hold and animal waste from households upstream. Many people had seen *Biomphalaria* swept into their cooking pots and laundry pans by bica water and thus had a good understanding of its seasonal occurrence. Snails and ova were commonly found on rocks, wooden planks, on leaves and in organic matter from food rests, which were the major form of pollution and a predictor of snail occurrence (Table III, Fig. 4). Ten *S. mansoni*-infected snails were col-

lected at 2 bicas used for bathing. Presence of ducks was associated with the absence of snails in the immediate vicinity of 3 bicas but not beyond 20 m upstream and downstream from these collection points, outside the range of ducks.

Fish ponds - The 53 of the 62 fishponds which yielded no *Biomphalaria* had large tilapia, as ascertained by our observations and information from homeowners. Seventeen of these ponds were said to contain also 8 other fish species, mostly catfish, "cará", "lumbari" and "traíra", all of which were smaller than tilapia. However, homeowners were not always knowledgeable about the presence of fish species other than tilapia, the major species they raised for food. Six ponds were devoid of fish, either because they had not been restocked after fish harvest or the fish had died due to excessive pollution by sewage causing anaerobic conditions or from predation by birds and snakes. Three of the 9 ponds populated by *Biomphalaria* contained "cará", "lumbari" and small tilapia recently introduced into one pond. Fishponds containing tilapia were also free of submerged and emerging vegetation, algae and pond scum.

Presence of fish was a predictor of *Biomphalaria* presence only in fishponds (Tables II, III). No association was found between snail presence and water source or size or depth of ponds. The negative association between tilapia and *Biomphalaria* was also noticed in Córrego do Xódos, where a homeowner stocked only one of his two ponds at a time with tilapia. The pond without tilapia in August had hundreds of large snails, as did the other pond devoid of fish in March (Figs 1, 5). A pond without fish for more than 2 years and fed by canal water in Limoeiro had the largest number of *Biomphalaria* in any pond (an estimated 20,000 or 200 snails per square meter). Three fishponds accounted for 86.6% of all *Biomphalaria* found in this habitat. More than half of all ponds received the effluent from nearby bicas, many of them inhabited by *B. glabrata*, or sewage from pigpens in an effort to provide organic matter for fish fattening. The owners of two ponds containing *Biomphalaria* emptied them spontaneously after learning about the presence of schistosomiasis intermediate host snails. Two *B. glabrata* were found to shed *S. mansoni* cercariae in 1 pond without fish during preliminary surveys in March 1999.

Wells - Neither snails of any species nor any other larger aquatic animals were found in the 5 shallow wells (Fig. 6). They were between 3 and 5 m deep and 3 of them were covered by boards or plastic and 2 had electric pumps. All wells were used as a supplemental source of water, due to the cost of pumping, the labor involved in pulling up water, and the generally high iron content of well water.

Tanks - The 10 tanks ("caixas") used by humans and the 6 tanks used by cattle received water from springs, streams and canals. One tank on a roof and 4 cement tanks used for household purposes, as well as 3 cattle tanks had *B. glabrata*. Tanks supported the largest mean number of snails of any habitat (Table I), inflated by two cattle tanks containing several hundred of snails each. The positive tank in Rua da Grota distributed water to five houses and the one in Rua dos Marinho to 6 houses via plastic pipes. No association was found between water source and snail presence but maintenance of tanks was a factor. Tanks that were frequently cleaned had relatively fewer snails and less silt and algae. A cattle tank on a large dairy farm in Rua da Estrada treated monthly with lime ("cal") was free of snails, unlike the adjacent untreated ones. A tank in Limoeiro fed by a spring via a half-kilometer long plastic pipe had *B. glabrata* (Figs 1, 7).

Rice fields - The small canals in three of the four rice fields were used during the rice growing season from November to April and contained *B. glabrata*. Flood-irrigated rice fields in the fourth rice field, in a swampy area of the main stream valley were found to be free of snails. However, they probably contain snails when flooded by the stream, as indicated by the presence of *Biomphalaria* in the adjacent swamp and information obtained from rice farmers and fishermen (Fig. 7).

Drains - The two of the four drainage canals below rice fields and the four of the five drain sites on cattle pastures were *Biomphalaria*-positive. Snail density was lowest in March, shortly after canal cleaning (Fig. 7).

Swamps - The three swamps in the stream bottom in the main valley and in Bom Jardim were seasonal swamps inundated by stream water during the rains. They developed eutrophic conditions when the water receded during the dry season, which was corroborated by the dense swamp grass and the near-absence of *Biomphalaria* and other aquatic animals. Only one live snail, no ova and many empty shells were found. The other two swamps were small, permanent snail habitats located on stream margins (Fig. 7). One of them contained *Biomphalaria* ova.

Seepage ponds - The 2 permanent seepage ponds adjacent to streams were densely vegetated with submerged and emerging aquatic plants and contained numerous large *B. glabrata* (Fig. 6). Both ponds were seasonally inundated by stream water.

DISCUSSION

Results of this longitudinal spatial study strongly indicate that connectedness and interde-

pendency of the different snail habitats, rainfall patterns and certain human activities facilitate the wide distribution of *Biomphalaria* in Melquiades. The numerous springs, small streams and the canals with their bicas appear to be the major breeding habitats of snails in Melquiades as indicated by the spatial and temporal distribution of snails. They supply the tanks, swamps, rice fields, drains and seepage ponds with *Biomphalaria* especially during accelerated snail dispersion in the rainy season. Annual fluctuations in rainfall and the creation and modification of man-made habitats and improvements in water supply and sanitation may thus affect the distribution of *Biomphalaria*. Use of bicas for washing utensils and laundry, the common practices of nutrient recycling in fishponds and diversion of untreated sewage into the streams may facilitate snail habitats and increase the risk of schistosomiasis transmission. These and other forms of nutrition recycling involving chicken, pigs and fish are widely practiced by subsistence and commercial farmers in Brazil and need to be studied for their pollution hazard.

Wells are not part of this dynamic snail distribution system due to their location on higher ground, away from the flooding streams, and possibly their water chemistry and lack of vegetation and pollution. Of the more than 30 wells we studied in two other rural communities in northern Minas Gerais only one well was found to contain *Biomphalaria*, in the rural village of Boa União north of Governador Valadares city (unpublished data). Absence of snails from the developed springs at lower elevations appears to be due to similar factors, because of the similarity of physical characteristics of these two water sources, but this needs further study. Springs are the preferred water source in Melquiades and other rural communities in much of Brazil.

The high level of people's knowledge of *Biomphalaria* occurrence at their water contact sites and their concern over schistosomiasis transmission have different implications for schistosomiasis control. On the one hand, these results would argue for greater involvement of local populations in the design and implementation of schistosomiasis control programs using the primary health care approach. People in Melquiades showed great interest in the snail surveys and expressed a desire for potable water and sanitation facilities. We were able to locate a number of sites in swamps, streams and drains that contained *Biomphalaria* with the help of two farmers. The farmer who applied lime to his cattle tanks had done so periodically for several years, after having talked to a veterinarian. Natural *S. mansoni* infections in cattle have repeatedly been reported from Brazil and lime

has been used by farmers as an effective, non-toxic molluscicide for many years in Brazil (Naftale Katz pers. commun.) but no detailed studies or control programs have been initiated (Mott et al. 1995). On the other hand, some studies in rural Brazil have reported a preoccupation with snails as the central force in schistosomiasis transmission that may interfere with control programs by diverting attention away from water supply, sanitation and other control measures (Rozemberg & Barbosa 1997).

Absence of *Biomphalaria* from all fish ponds stocked with adult tilapia strongly indicates that this fish is an effective biological control agent in Melquiades. Our results also corroborate the long-held view that management of fish ponds is critical in keeping them free of schistosomiasis intermediate hosts (Berrie 1965, Ferguson and Ruiz-Tieben, 1971). Use of canal or stream water in ponds and failure to stock them with tilapia constitute *S. mansoni* transmission risks in Melquiades. Follow-up studies are being planned to identify the species of tilapia involved in Melquiades. The impact of guppies (*Lebistes reticulatus*), which are common in Melquiades, could not be assessed. Several laboratory studies showed that this fish is an efficient predator of *S. mansoni* cercariae (Pellegrino et al. 1966, Knight et al. 1970). Our results of the impact of ducks on snail occurrence are inconclusive due to possible sampling error and the small number of households keeping ducks. The schistosomiasis control program in Brazil includes the introduction of ducks, which have been shown to be effective in reducing *Biomphalaria* around houses (Naftale Katz, pers. commun. 1999).

This preliminary spatial analysis of *Biomphalaria* distribution is to be followed with interactive mapping of snails, water supplies, water contact patterns and environmental data in an effort to model *S. mansoni* transmission and reinfection in both snail and humans as part of the ongoing epidemiological study.

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