The impact of the local water-development programme on the abundance of the intermediate hosts of schistosomiasis in three villages of the Senegal River delta

BY J.-C. ERNOULD*, K. BA
Centre ORSTOM, B.P. 1386, Dakar, Senegal
AND B. SELLIN
CERMES/OCCGE/ORSTOM, B.P. 10887, Niamey, Niger

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The populations of the potential intermediate hosts of Schistosoma mansoni and S. haematobium were studied for a year at transmission sites near three villages in the lower delta of the Senegal River. Biomphalaria pfeifferi, found to be widely distributed and increasingly abundant, appears to be well adapted to the new areas of irrigation (created by the dams at Diama and Manantali) thanks to its ability to withstand changes in temperature and to aestivate. This species is responsible for intense transmission of S. mansoni during the rainy season. In contrast, Bulinus globosus, the species responsible for the transmission of S. haematobium (which occurs during the dry season), had a more limited distribution. The changing distributions of these two snail species appear to be linked to changes in local ecology, themselves the result of the recent programme of water-development in the delta.

Following a period of drought in the area in the 1970s, a programme of water development was initiated in the Senegal River valley to control water flow and increase agricultural output. The dam of Diama, near the mouth of the river, has protected the delta from salt-water intrusion during the dry seasons since 1986. The dam at Manantali (in Mali), on the Bafing River (a higher tributary of the Senegal River) has had a major influence on the flow of the Senegal River since the dam’s completion in 1988. Although both dams have helped to stabilise the flow of water and increase the surface area covered by freshwater, they have also led to increases in the populations of the aquatic snails that are the intermediate hosts for the parasites causing human schistosomiasis.

Before construction of the dams, only urinary schistosomiasis was endemic in the Senegal valley. Schistosoma haematobium, the causative agent of this disease, was common in the middle valley (Chaine and Malek, 1983; Vercruysse et al., 1985, 1994), where it was mostly transmitted by Bulinus senegalensis living in temporary pools (Malek and Chaine, 1981). Two foci—at Guédé Chantier (middle valley), where the intermediate host was Bu. senegalensis (Vercruysse et al., 1985), and at Lampsar (lower delta), where the intermediate host was Bu. globosus (Malek and Chaine, 1981)—were related to irrigation schemes. Bulinus truncatus, which was widespread in the valley (Malek and Chaine, 1981; Vercruysse et al., 1985), apparently played no part in the transmission of the local strain of S. haematobium (Southgate et al., 1985). A few Biom-
phalaria pfeifferi were observed around Guiers Lake, south of Richard Toll (Diaw, 1980; Malek and Chaine, 1981).

After the dams became operational, this epidemiological situation changed rapidly. Colonization of the irrigation channels at Richard Toll by Bi. pfeifferi allowed the emergence of an important urban focus of intestinal schistosomiasis (Talla et al., 1990). The focus of urinary schistosomiasis in the lower delta extended upstream from 1989, due to the colonization by Bu. globosus of the areas under irrigation (Verlé et al., 1994). The results of several surveys performed in January 1994 (Picquet et al., 1996) revealed an extension of the distribution of S. mansoni which overlapped that of S. haematobium, creating a mixed focus of S. haematobium and S. mansoni infection. The aim of the present study was to investigate the current abundance of the potential intermediate hosts of the schistosomes in this mixed focus, in relation to environmental factors and season.

MATERIALS AND METHODS

Study framework

The Senegal delta, at about 16°N, spreads out from Richard Toll to Saint Louis, 120 km downstream (Fig. 1). The delta is formed by the Senegal River, interrupted by the dam of Diama, and two secondary rivers: the Gorom and the Lampar. The two secondary rivers are connected by a canal near Boundoum and this is kept full of water for most of the year—by the rivers during the rainy season (a mean of 100 mm of rain falling between July and October) and by the pumping of water from the Senegal River during the dry season. However, the pumped water is insufficient to prevent a fall in water level in the canal by the end of the dry hot season (March–June). The mean daily temperature in the area varies from 20°C in January to 30°C in June. The population of the lower delta lives around the canal, which acts as an hydraulic axis and source of water for irrigation and the growing of two crops of rice/year.
Selection of Survey Sites
The transmission sites for three villages in the mixed S. haematobium/S. mansoni focus in the delta were surveyed (Fig. 1): Boundoum (upstream) where S. mansoni predominates; Diagambal (middle) where S. haematobium and S. mansoni are both in abundance; and Savoigne (downstream) where S. haematobium predominates. The malacological survey investigated 12 water-contact sites used regularly by the populations in the three villages: B1-B4 in Boundoum; D1-D4 in Diagambal; and S1-S4 in Savoigne. Two of these sites (D1 and S1) were also used by livestock.

Boundoum (1538 inhabitants) lies by the Lampsar River, where it is wide, deep and continually flowing. Three of the main sites of water contact (B1-B3) are situated on the steep muddy bank of the river, exposed to the flow, whereas the fourth (B4), further upstream, is in a sandy cove with relatively shallow water.

Diagambal (603 inhabitants) is situated 2 km from the left bank of the Lampsar River. One of the sites (D1) lies next to the shady, muddy, gently sloping river bank, covered in vegetation. The two main sites (D2 and D3) are situated in the irrigation channel which borders the village and holds water from April–December. The vegetation which has invaded this shallow (1 m) and narrow (2 m) channel has slowed the flow of water. D4 is situated 500 m from the village on a drainage channel with steep banks which limit access.

Savoigne (821 inhabitants) lies 2 km from the right bank of the Lampsar River, by an irrigation channel which partially dries at the end of the dry season. All the study sites at Savoigne are on this channel and all but the most upstream one (S1) are heavily shaded.

Methods
The 12 selected sites were investigated every 15 days from March 1994 to February 1995. On each occasion and at each site, water temperature, pH and conductance were measured and aquatic snails were hand collected for 15 min. Snails were identified by shell morphology, according to the simplified key of Brown and Kristensen (1991). Each snail found to be a potential host for S. haematobium or S. mansoni was checked for infection by placing it in a container of filtered river water at 08.00 hours and checking the water for cercariae between 14.00 and 17.00 hours on the same day. The gender of any cercariae shed was identified using the key of Frandsen and Kristensen (1984). As Bu. globosus is locally resistant to S. bovis (Southgate et al., 1985), any Bu. globosus found infected were assumed to be carrying S. haematobium. All non-infected snails were returned to their habitat.

RESULTS
Site Characteristics and Snail Abundance
Data on water temperature, pH and conductance are summarized in the Table. Four species of intermediate host were observed in the survey sites: Bi. pfeifferi; Bu. truncatus; Bu. globosus; and Bu. forskali.

Biomphalaria pfeifferi
Biomphalaria pfeifferi was abundant at all the sites at Boundoum and on the perimeters of Diagambal (D2–D4). At Boundoum it was present throughout the year but numbers peaked between June and December (Fig. 2). At Diagambal it was always found in the drainage channel (D4) but was seasonal in the irrigation channel where the first adults were observed in May (Fig. 3). This species was observed only irregularly at Savoigne (S4; Fig. 4).

Bulinus truncatus
Bulinus truncatus was generally abundant and omnipresent (Figs 2, 3 and 4), its numbers decreasing between August and December at all sites except those on the Diagambal irrigation channel (D2 and D3) where it remained abundant until December (Fig. 3).

Bulinus globosus
Bulinus globosus was relatively less abundant and its presence was limited mainly to the Savoigne channel and to the river at Diagam-
### Table


<table>
<thead>
<tr>
<th>Site(s)</th>
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<th>Mean temperature (°C)</th>
<th>Mean pH</th>
<th>Mean conductance (μS)</th>
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<td>29.2</td>
<td>19.5</td>
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</table>
Fig. 2. Seasonal variation in the numbers of uninfected *Biomphalaria pfeifferi* (■), *Bulinus truncatus* (■■) and *Bu. globosus* (■) and infected snails of the same species (■■) collected at the transmission sites of the village of Boundoum from March 1994 until February 1995.
Fig. 3. Seasonal variation in the numbers of uninfected Biomphalaria pfeifferi (O), Bulinus truncatus (■) and Bu. globosus (□) and infected snails of the same species (■) collected at the transmission sites of the village of Diagbal from March 1994 until February 1995.
Fig. 4. Seasonal variation in the numbers of uninfected Biomphalaria pfeifferi (□), Bulinus truncatus (■) and Bu. globosus (□) and infected snails of the same species (■) collected at the transmission sites of the village of Savoigne from March 1994 until February 1995.
Bulinus forskalii
A few specimens of *Bu. forskalii* were observed in October at Savoigne and in the river at Diagambal (D1).

**Snail Infection**

*Biomphalaria pfeifferi*, *Bu. globosus* and *Bu. truncatus* were found naturally infected with *S. haematobium* or *S. mansoni*.

**Biomphalaria pfeifferi**
Infected *Bi. pfeifferi* were present throughout the year at Boundoum (Fig. 2), the rate of infection peaking in June–September, when it reached 19% (compared with ≤5% for the rest of the year).

At Diagambal (Fig. 3), *Bi. pfeifferi* were found infected in the irrigation channel 4 months after its flooding and the infestation rate, although initially low (2%), increased from October onwards (to 8%). In the drainage channel, some specimens were found infected between January and June.

**Bulinus globosus**
Infected *Bu. globosus* were found between February and June at Savoigne and in the river at Diagambal (D1) (Figs 3 and 4). Although often found infected, the numbers of this species remained low.

**Bulinus truncatus**
Some infected *Bu. truncatus* were found between October and February at Boundoum and on the perimeter of Diagambal, and at Savoigne between March and June (Figs 2, 3 and 4). However, the overall infection rate was low (2%).

**DISCUSSION**

The present results indicate that *Bi. pfeifferi* has become well established in the lower delta. This intermediate host is particularly abundant in the upstream part of the hydraulic axis and in the irrigation network of Diagambal, where its numbers peaked during the rainy season. Its presence in the median reach and at Savoigne appears less important.

In comparison with *Bi. pfeifferi*, *Bu. globosus* is less abundant and limited to the downstream part of the lower delta. *Bulinus truncatus* is widespread and is most abundant in the dry season, in the upstream part of the axis and on the perimeters of Diagambal. *Bulinus forskalii* was only observed rarely, in the median reach and at Savoigne.

Like the total numbers of this snail, the numbers of *Bi. pfeifferi* infected with *S. mansoni* (and presumably, therefore, transmission of *S. mansoni* to the local villagers) peaked during the rainy season. The numbers of infected snails collected indicate that transmission is probably continuous upstream, seasonal in the median reach (beginning 4 months after the flooding of the irrigation channel at Diagambal) and not occurring in the downstream part of the delta.

The transmission of *S. haematobium* in the delta of the Senegal River, attributed entirely to *Bu. globosus* (Chaine and Malek, 1983), appears to occur mainly during the dry season and at moderate intensity. In the present study, some schistosome-infected *Bu. truncatus* were found at sites at which no animals are watered but it seems inappropriate to assume that these snails carried *S. haematobium* since the local strain of this parasite and *Bu. truncatus* appear incompatible (Rollinson et al., 1997).

The seasonal variations in the populations of intermediate hosts may reflect variation in water salinity, level and temperature, and in vegetation.

**Salinity**

The dam at Diama now protects the lower valley from the intrusion of seawater, as attested by the low conductivity of all water samples collected in the hydraulic axis. Much of the land in the delta remains salted, however, and water draining from this land, such as that in the drainage channel at Diagambal, may have quite high conductivity (around 2000 µS/cm). Such high conductivities do no prevent multiplication of *Bu. truncatus* in the...
dry season or the permanent presence of *Bi. pfeifferi*. The absence of *Bu. globosus* from the Diagambal drainage channel may reflect the relatively low tolerance of this species and others in the *Bulinus africanus* group to salt, as indicated by the results of experiments performed on *Bu. africanus* itself (Donnelly *et al.*, 1983). However, the fact that *Bu. globosus* is not very abundant in the low-salt environments of the hydraulic axis and irrigation channels suggests that salt is not the only factor limiting its distribution.

**Water Level**

The more regular supply of water to the hydraulic axis, facilitated by the more stable flow of water in the adjoining rivers since the building of the Manantali dam, appears to have supported long-term multiplication of *Bi. pfeifferi* in the upstream section. The greater, seasonal fluctuations in water level in the downstream section may be impeding its permanent colonization by *Bi. pfeifferi*; this could explain the repeated observation of low numbers of this snail in this area since 1991 (Deme, 1993; Verlé *et al.*, 1994). The regulation of the flow along the axis has cut the period when the irrigation channels fed by the axis are completely dry each year from 7 to 3 months. As *Bi. pfeifferi* is able to aestivate for 3 months (Cridland, 1967), adults of this species are now able to survive the drying out of the channels and commence multiplication as soon as the channels are re-filled. *Biomphalaria pfeifferi* and *Bu. truncatus* must go into a state of anhydrobiosis during the drying out of the channels. The low resistance of *Bu. globosus* to drought (Cridland, 1967) may explain why adults of this species were not collected from the irrigation channel at Diagambal immediately after this channel was re-filled.

**Water Temperature**

Water temperature is an obvious limiting factor in the speed of multiplication of any snail species. That populations of *Bi. pfeifferi* in the lower delta increased rapidly during the dry, hot season indicates that this species is relatively resistant to hot temperatures (30–32°C). In contrast, most multiplication by *Bu. truncatus* occurs in the cooler months, decreasing as the rainy season begins; this 'preference' for relatively low temperatures confirms previous observations in Nigeria (Betterton, 1984). [The ability of *Bu. truncatus* to reproduce rapidly post-aestivation (Oyeyi and Ndifou, 1990) may explain the paradoxical presence of this species in the Diagambal irrigation channels during the hot, dry season.] The relatively small numbers of *Bu. globosus* collected during the rainy season may also be linked to inhibition of this species' growth and reproduction in water at relatively high temperatures (O'Keefe, 1985). As water temperatures in the delta generally increased with distance from the sea (Raes and Sy, 1992), relatively high water temperatures may have prevented *Bu. globosus* from colonizing the upstream section of the hydraulic axis before the dams filled. The rise in water level since the dams were completed has reduced the gradient in water temperatures and cooled the water in the upstream section of the axis, presumably helping the progression of *Bu. globosus* towards the middle of the delta. It is unclear, however, why this species is absent further upstream, which is better supplied with water.

**Vegetation**

Lush vegetation was a common feature of the various sites where *Bu. globosus* was regularly observed and may help the development of this species. The relative rarity of *Bi. pfeifferi* at the same sites may be linked to shading by the plants (Loreau and Baluku, 1991); this could also explain the irregular collection of this species from the most shaded sites on the irrigation channel at Savoigne and the apparent absence of this species from the downstream sites on the Lampsar River (the banks of the downstream section of this river having much denser tree growth than those upstream).

**Schistosomiasis and Water Development**

The recent developments in the Senegal River valley have deeply modified both the flow of the delta waters (via the Manantali dam) and
their quality (via the Diama dam). The control of flow has allowed a more regular supplying of the hydraulic axis and this, in turn, has allowed the annual period of irrigation to be extended. This change seems to have been particularly favourable to *B. pfeifferi*, the intermediate host of *S. mansoni*; the increased stability in water level has allowed this snail to be present continually in the upstream section of the hydraulic axis and the longer irrigation period has permitted it to colonize the irrigation network. In contrast, *B. globosus*, the intermediate host of *S. haematobium*, only seems to have benefitted slightly from these transformations in the environment because of its relative intolerance of high temperatures. In consequence, an important focus of *S. mansoni* infection has developed in the upstream section of the axis whereas the focus of *S. haematobium* remains restricted to the downstream section. The level of *S. mansoni* transmission is particularly high in the irrigated areas during the rainy season because human-water contact and the density of *B. pfeifferi* in the irrigation channels are both high then. Chemotherapy should commence at the beginning of the dry, cold season, at a time when the transmission of *S. mansoni* is inhibited and that of *S. haematobium* has yet to be established. Breaks in the supply of the hydraulic axis and the introduction of a drying-out period between the two rice crops could limit the proliferation of intermediate hosts.

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REFERENCES


IRRIGATION AND SNAIL ABUNDANCE IN SENEGAL


