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Association of riverine prawns and intermediate host snails and correlation with human schistosomiasis in two river systems in south-eastern C te d'Ivoire

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Abstract

The current emphasis of schistosomiasis control is placed on preventive chemotherapy using praziquantel. However, reinfection may occur rapidly in the absence of complementary interventions. Recent studies from Senegal suggest that predatory prawns might feed on intermediate host snails and thus impact on schistosomiasis transmission. We designed a study with four repeated cross-sectional surveys pertaining to prawns and snails, coupled with a single cross-sectional parasitological survey among humans. We assessed for potential associations between the presence/density of prawns and snails and correlation with *Schistosoma* infection in a composite sample of school-aged children and adults. The study was carried out between October 2015 and December 2016 in 24 villages located near the Agn by and M  coastal river systems in south-eastern C te d'Ivoire. At each site, snails and prawns were collected, and in each village, 150 individuals were subjected to stool and urine examination for the diagnosis of *Schistosoma mansoni* and *S. haematobium*. We found peaks of relative abundance of intermediate host snails in the villages of the Agn by River system, while predatory prawns were predominantly recorded in the M  River system. A negative association was observed between intermediate host snail densities and riverine prawns; however, no pattern was found between this trend in the predator–prey relationship and the prevalence of human schistosomiasis.

Introduction

Schistosomiasis continues to be a public health problem, particularly in sub-Saharan Africa (Colley *et al.*, 2014; WHO, 2017). A striking 779 million people are at risk of schistosomiasis, with more than 250 million people being infected with at least one *Schistosoma* species. Schistosome-related disease causes an estimated global burden of 1.9 million disability-adjusted life years (DALYs) in 2016 (Steinmann *et al.*, 2006; Hotez *et al.*, 2014; GBD 2016 DALYs and HALE Collaborators, 2017).

A key epidemiological feature of schistosomiasis is the focal distribution, which is governed by human behaviour (e.g. open defecation and human–water contact patterns) and social–ecological systems (e.g. poverty and living in close proximity to natural or man-made water bodies inhabited by intermediate host snails) (Utzinger *et al.*, 2011; Lai *et al.*, 2015). In C te d'Ivoire, both intestinal schistosomiasis (caused by an infection with *Schistosoma mansoni*) and urogenital schistosomiasis (caused by *S. haematobium*) are endemic, and the disease is transmitted by three intermediate host snail species; namely, *Biomphalaria pfeifferi* (transmitting *S. mansoni*) and *Bulinus globosus* and *Bu. truncatus* (transmitting *S. haematobium*) (N'Goran *et al.*, 1989; Tchuem Tchu nt  and N'Goran, 2009; Chammartin *et al.*, 2014).

Over the past 15 years, control and elimination of schistosomiasis has been stepped up with preventive chemotherapy serving as the backbone of interventions (WHO, 2002, 2017). Preventive chemotherapy refers to the periodic administration (e.g. once a year) of praziquantel to at-risk groups (e.g. school-aged children) without prior diagnosis (WHO, 2006). Unfortunately, praziquantel-based morbidity control, applied on its own, has limitations owing to the risk of rapid reinfection and the lack of control over mass treatment frequency and coverage (Garba *et al.*, 2013; Tchuem Tchu nt  *et al.*, 2013). In this context, the World Health Organization (WHO) communicated the need for new approaches to control the intermediate host snails and the possibility of integrating them into already existing control strategies. Studies carried out in the 1980s and 1990s emphasized the need for complementary strategies, such as biological control (e.g. competitor snails and crayfish), chemical control (e.g. use of niclosamide) and environmental management that target the intermediate host snails (McCullough *et al.*, 1980; McCullough, 1981; Pieri and Thomas, 1987; Lardans and Dissous, 1998; Mkoji *et al.*, 1999). Limitations of these approaches include financial constraint

(e.g. high capital investment of environmental management) and ecological liability (e.g. niclosamide is toxic for non-target fauna, such as fish). Recent studies in Senegal and Egypt suggest that the rehabilitation of ecosystems and the reintroduction of predatory riverine prawns reduce snail populations, and might thus have an impact on schistosomiasis transmission (Khalil and Sleem, 2011; Sokolow *et al.*, 2014, 2015).

Against this background, the Schistosomiasis Consortium for Operational Research and Evaluation (SCORE) has funded a study in Côte d'Ivoire with two specific aims: (i) to determine the relationship between native riverine prawns and intermediate host snails (presence and density) and (ii) to explore associations between specific native riverine prawns (e.g. *Macrobrachium* spp.), intermediate host snails of schistosomiasis and the prevalence of *Schistosoma* infection in humans. The investigation was carried out in two purposely selected coastal river systems in the south-eastern part of Côte d'Ivoire (Da Costa *et al.*, 2000; N'Zi *et al.*, 2003; Bony *et al.*, 2013). Our study aimed at contributing to the characterization of a complex predator–prey system under field conditions to deepen the understanding of schistosomiasis transmission.

Materials and methods

Ethics statement and treatment

The study was approved by the national ethics committee of Côte d'Ivoire (reference no. 114/MSLS/CNER-dkn). Additionally, approval was obtained from local health and village authorities of Adzopé and Agboville. Village committees were informed about the objectives, procedures and potential risks and benefits of the study. Written informed consent was obtained from adult participants and from parents/guardians of minors (aged <18 years). Participants diagnosed with *Schistosoma* infection were treated with a single 40 mg kg⁻¹ oral dose of praziquantel, and soil-transmitted helminth infections were treated with single 400 mg oral albendazole free of charge by the national schistosomiasis and soil-transmitted helminthiasis control programme (WHO, 2002, 2006).

Study area

The study was carried out between October 2015 and December 2016 in 24 villages in two purposely selected coastal river systems located in the districts of Adzopé and Agboville in the south-eastern part of Côte d'Ivoire (geographical coordinates: 5°35' to 6°15'N latitude; 3°55' to 4°40'W longitude). The key selection criterion for villages was close proximity (<3 km) to either the Agnéby River or the Mé River (Fig. 1). Of note, a national survey pertaining to predatory riverine prawns revealed the presence of prawns in these two coastal river systems (N'Zi *et al.*, 2003).

The climate is hot and humid with daily average temperature ranging between 24.9 and 33.6 °C and an average annual precipitation between 1298 and 1739 mm. The two hydrological systems are characterized by hills and wide valleys, interspaced by marshlands. There are four seasons: a short rainy season from September to November, a long dry season from December to March, a long rainy season from April to mid-July and a short dry season from mid-July to August. The natural vegetation is dense tropical rain forest. People are mainly engaged in subsistence agriculture (e.g. banana, cassava and vegetable farming). Fishing is done in both river systems.

Study design

We pursued a cross-sectional study design. In brief, we conducted four combined prawn and snail surveys, one per season, and

determined the presence and density of prawns and snails, identified at species level. Additionally, a single parasitological survey was carried out in January 2016 to determine the prevalence of *S. haematobium* and *S. mansoni* among school-aged children and adults in each of the 24 villages.

Environmental and physico-chemical parameters

Physico-chemical parameters of water bodies where prawns and snails were sampled were determined, using standard protocols (Utzinger *et al.*, 1997). Measurements were made *in situ* prior to snail and prawn sampling. Conductivity ($\mu\text{S cm}^{-1}$), water temperature (°C), pH, total dissolved solids (TDS, mg L⁻¹), water resistivity (k $\Omega\text{ cm}^{-1}$), salinity (‰) and redox potential (mV) were recorded, using a multi-parameter apparatus (HQ 30d; Hach, Loveland, CO, USA). The parameters assessed for microhabitat characterization included water velocity (m s⁻¹), vegetation cover (%), presence of dead wood and bamboo and substrate type (e.g. mud, sand or gravel). The latter parameters were visually determined.

Snail and prawn surveys

Villagers were asked about human–water contact sites, defined as open water bodies that are used for domestic purposes (e.g. washing clothes and dishes and fishing) or recreational activities (e.g. swimming and bathing). Human–water contact sites were georeferenced, using a hand-held global positioning system (GPS) device (Garmin eTrex 10). Cross-sectional surveys were conducted by experienced teams for collection of snails and prawns adhering to standard protocols (WHO, 1998; Diakité *et al.*, 2017). In short, snails were sampled by two field collectors for a period of 15 min using scoops and forceps. Snails identified as potential intermediate hosts of schistosomiasis based on morphological characteristics (WHO, 1998) were transferred on water-soaked cotton in perforated plastic boxes to a laboratory at the Université Félix Houphouët-Boigny. In the laboratory, snails were subjected to the cercarial shedding test after exposure of snails to artificial light for 2–3 h starting at 09:00 h. Cercariae were morphologically identified using readily available identification keys (Frandsen and Christensen, 1984).

Prawns were collected by a team consisting of four people, one holding an electroshock device and three collectors. We employed an electric fishing device powered by a 12 V and 24 A rechargeable battery (Rundumfisch AG; Altendorf, Switzerland). The generator delivers either direct current or an alternating current between two electrodes (N'Zi *et al.*, 2015). Each electroshock collection lasted 15 min. Note that prawns exposed to electrical pulses stimuli show strong, immediate reactions, leaving them floating at the surface. Prawns were then collected with a long-handled net (diameter: 25 cm; mesh size: 2 mm) by another operator. Prawns were placed into a plastic bottle and preserved in 70% ethanol. Bottles were labelled with the name of the site and the time of capture. The filled and labelled bottles were transferred to a laboratory at the Université Félix Houphouët-Boigny. Species identification of prawns was done using available identification keys (Monod, 1981). Additionally, measurements were taken at the nearest 0.1 mm, using a Mitutoyo caliper. After species identification, prawns were counted and weighed individually.

Parasitological survey

A sample size of 150 individuals, composed of 100 children aged 9–12 years and 50 adults aged 20–55 years, was the pre-set target for the cross-sectional parasitological survey in each village. Children were directly recruited in the schools, while adults were randomly selected from participating households. Stool

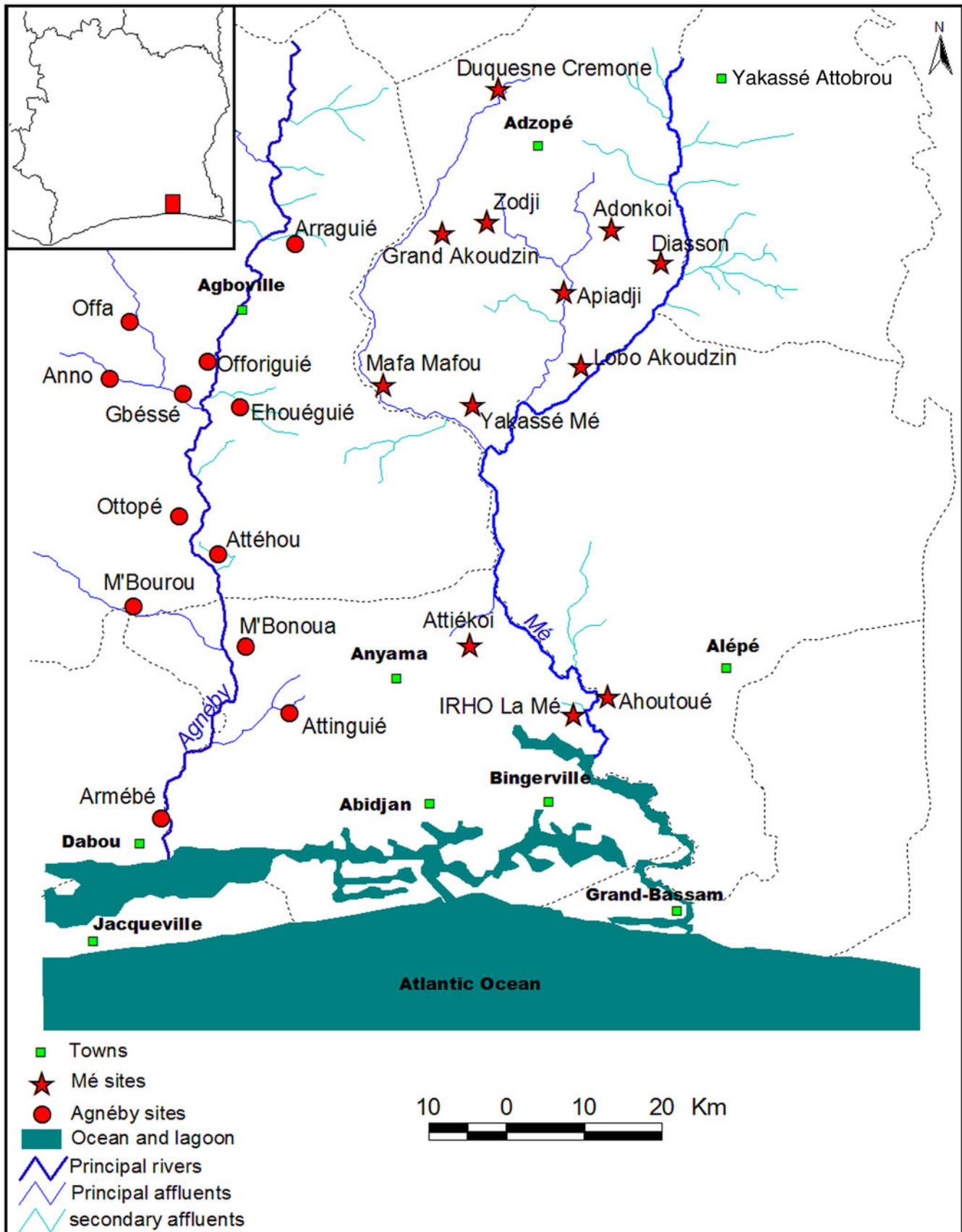


Fig. 1. Map of the study area with the two coastal river systems Agnèby and Mé in Adzopé and Agboville in south-eastern Côte d'Ivoire.

and urine samples were collected between 10:00 and 14:00 h at schools and the village health centre. All samples were transferred to the health district laboratories of Adzopé and Agboville and worked-up the same day.

The urine filtration method was used for the detection of *S. haematobium* eggs. In brief, urine samples were vigorously shaken, 10 mL were filtered through a polyamide filter (diameter: 13 mm; mesh size: 20 μ m) and stained with a drop of Lugol's

solution. The samples were examined under a microscope by experienced laboratory technicians and eggs of *S. haematobium* counted (Utzinger *et al.*, 2011). Stool samples were subjected to duplicate Kato–Katz thick smears using 41.7 mg standard templates. The slides were allowed to clear for 30–45 min prior to examination under a microscope by experienced laboratory technicians. The number of *S. mansoni* eggs (and species-specific soil-transmitted helminth eggs) were counted and recorded for each species separately (Utzinger *et al.*, 2011).

Statistical analysis

All analyses were conducted using the statistical environment R (R Foundation for Statistical Computing; Vienna, Austria). The prevalence of *Schistosoma* infection in humans was analysed with generalized estimating equation models for binary outcomes to adjust for potential correlation within villages. To assess whether prawns and intermediate host snails share the same habitats, a canonical correspondence analysis was conducted. The analysis was restricted to those human–water contact sites where complete data records were available. The canonical correspondence analysis (scaling type 2, i.e. species scaling) was done using the package ‘vegan’. The following 14 parameters were included: water temperature, pH, TDS, water resistivity, redox potential, water velocity, clearness, water level, vegetation cover, presence of dead wood and bamboo, characterization of aquatic vegetation and three types of substrate.

Results

Snail abundance

A total of 14 235 freshwater snails were collected in four cross-sectional surveys, conducted at 108 human–water contact sites in 24 study villages at the two hydrological systems in the Agnéby and Mé rivers. At the unit of the village, the mean number of human–water contact sites ranged between two and nine. Identification based on shell morphology revealed 15 different snail genera. The two genera known to be intermediate hosts for schistosomiasis (i.e. *Biomphalaria* and *Bulinus*) were most abundant with 4263 (29.9%) specimens, while the remaining 9972 specimens (70.1%) belonged to 13 genera that do not act as intermediate host for human schistosomiasis in Côte d’Ivoire (i.e. *Bellamya*, *Ceratophallus*, *Ferrissia*, *Gabbiella*, *Gyraulus*, *Indoplanorbis*, *Lanistes*, *Lymnaea*, *Melanooides*, *Physa*, *Pila*, *Potadoma* and *Segmentorbis*).

During the four cross-sectional surveys, peaks of relative abundance of intermediate host snails, averaged across the four seasons assessed, were mainly recorded in villages located in close proximity to the Agnéby River (Fig. 2A). Particularly high intermediate host snail abundance was observed in Ehouéguié ($n = 1642$) and Offa ($n = 453$), while the lowest abundance ($n = 0$) has been observed in most localities. Two villages (Apiadji and Mafa Mafou) in the Mé River system were characterized by a considerably inferior presence of intermediate host snails compared with those observed in the Agnéby River system.

Biomphalaria pfeifferi and *Bu. globosus* were observed in all four seasons with the highest peak being recorded in the short rainy season and in the short dry season. *Bulinus truncatus* was observed only in two seasons with relatively lower abundance compared with *Bu. globosus* and *Bi. pfeifferi*. Noteworthy differences between the relative abundance of snails were observed according to season.

Prawns

A total of 4015 riverine prawns were obtained in the two river basins during the four cross-sectional surveys. Figure 2B shows

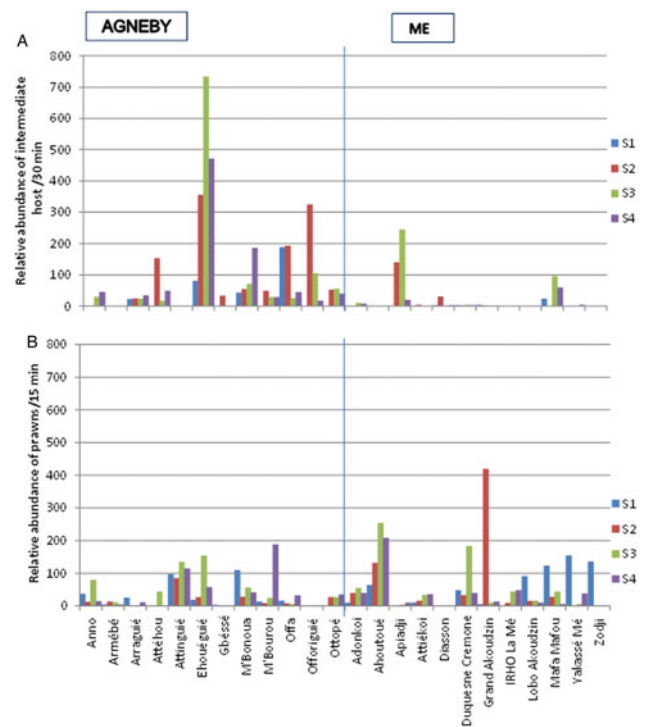


Fig. 2. Seasonal distribution of schistosomiasis intermediate host snails (A) and prawns (B) in the Agnéby and Mé River systems between October 2015 and December 2016. Relative abundance of snail per 30 min and relative abundance of prawns per 15 min. S1, short rainy season; S2, long rainy season; S3, short dry season; S4, long dry season.

the seasonal distribution of prawns in the Agnéby and Mé River systems. The prawns belonged to three genera and seven species. The genus *Caridina* with two species (*C. africana* and *C. nilotica*) was the most abundant with 53.0% of total specimens, followed by *Desmocarid trispinosa*, accounting for 42.6%. The genus *Macrobrachium* was quite rare (4.4%), represented by four different species (*Ma. dux*, *Ma. macrobrachion*, *Ma. raridens* and *Ma. vollenhovenii*). The highest densities of *Macrobrachium* prawns were observed in the Mé River basin, in the villages of Ahoutoué ($n = 659$) and Grand Akoudzin ($n = 450$). Additionally, in the Agnéby River basin, there was one village with a relatively high abundance of *Macrobrachium* prawns, namely in Attinguié ($n = 433$).

Dynamics of snail and prawn abundance

The relationship between the density of snails and prawns is shown in Fig. 3. In regard of the considerably lower abundance of the predatory prawns of the *Macrobrachium* genus, only the total population of all species of prawns was considered. Three major groups emerged from this analysis. A first group is characteristic for a strong superposition of sites with high density of prawns but no snails. A second group clusters sites with high densities of snails but no or only very few prawns. A third group of sites pertained to low densities of both snails and prawns. The largest proportion of snails shedding cercariae was found at sites characterized by high densities of snails and absence of prawns. However, a few sites with infected snails were found in the third group.

Relationship between environmental and physico-chemical factors and snail and prawn populations

The results from the canonical correspondence analysis are depicted in Fig. 4. Of note, the parameters varied according to the river system. The two intermediate host snail species *Bi. pfeifferi* and *Bu. globosus* and the prawn species *C. nilotica*

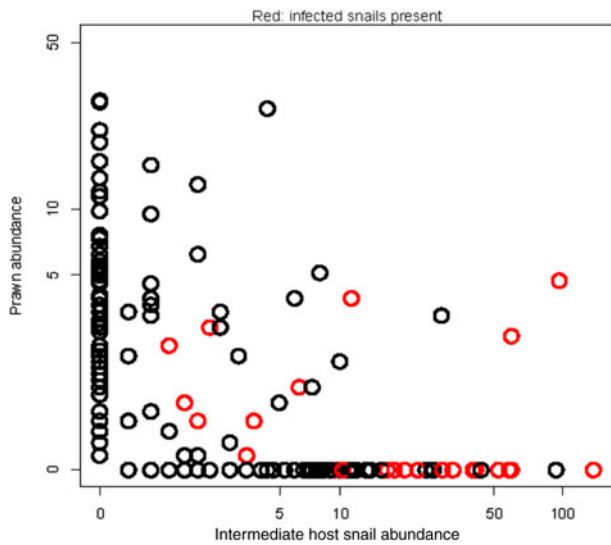


Fig. 3. Abundance of schistosomiasis intermediate host snails and prawns in the study sites in the Agnéby and Mé River systems sampled between October 2015 and December 2016. Black circles, human–water contact site without schistosome-infected snails; red circles, human–water contact site with schistosome-infected snails.

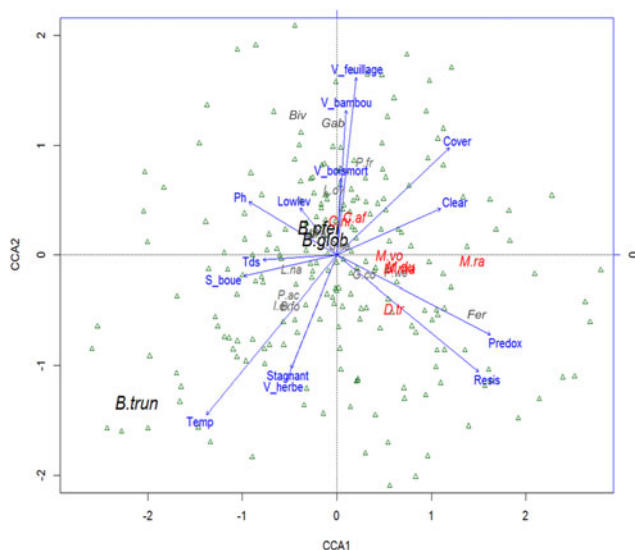


Fig. 4. Canonical correspondence analysis (CCA) for all snails and prawns collected in the various human–water contact sites and environmental parameters. Temp, temperature; Tds, total dissolved solids; Resis, resistivity; Predox, redox potential; Clear, clear water; Cover, coverage of water by aquatic vegetation; Stagnant, stagnant water; Lowlev, low level of water body; V_bambo, bamboo tree; V_bois mort, dead wood; V_feuille, canopy; V_herbe, submerged herbs of the river; S_boue, mud; *B.pfei*, *Biomphalaria pfeifferi*; *B.trun*, *Bulinus truncatus*; *B.glob*, *Bulinus globosus*; *Bel*, *Bellamya* sp; *C*, *Ceratophallus* sp; *Fer*, *Ferrissia* sp; *Gab*, *Gabbiella* sp; *G.ster*, *Gyraulus stercoralis*; *I.ex*, *Indoplanorbis exustus*; *L.ov*, *Lanistes ovum*; *L.na*, *Lymnaea natalensis*; *M.tu*, *Melanoides tuberculata*; *P.ac*, *Physa acuta*; *P.ov*, *Pila ovata*; *P.fr*, *Potadoma freethii*; *S.ka*, *Segmentorbis kanisaensis*; *Biv*, *Bivalva*; *C.af*, *Caridina africana*; *C.ni*, *Caridina niloticus*; *D.tr*, *Desmocarid trispinosa*; *M.du*, *Macrobrachium dux*; *M.ma*, *Macrobrachium macrobrachion*; *M.ra*, *Macrobrachium raridens*; *M.vo*, *Macrobrachium vollenhovenii*.

were positively correlated with TDS, pH, clear water, low water level, dead wood and bamboo, and negatively correlated with water temperature, redox potential and water resistivity. Species of *Ma. vollenhovenii*, *Ma. macrobrachion* and *Ma. dux* showed a positive relationship with redox potential, water resistivity, clear water and aquatic vegetation and were negatively correlated with pH, TDS and a low water level. The same trends observed annually did not vary between the four seasons.

Infection of intermediate host snails and schistosomiasis prevalence in humans

Snails shedding cercariae were identified in 10 of the 24 villages surveyed (six villages in the Agnéby River system and four in the Mé River system) in at least one of the four seasons. *Biomphalaria pfeifferi* and *Bu. globosus* infections were found in eight villages (33%), while mixed infections were observed in six villages (25%).

Table 1 shows the prevalence of *Schistosoma* infection in the 24 villages investigated. In total, there were 3338 participants (2378 school-aged children and 960 adults). Stool samples were provided by 3227 individuals (2319 school-aged children and 908 adults) and the presence of *S. mansoni* eggs was recorded in 381 of them (11.8%). Urine samples were available from 3204 (2306 school-aged children and 898 adults) participants and *S. haematobium* eggs were observed in 216 of them (6.7%). The prevalence of *S. mansoni* infection was significantly higher in the Mé River system compared with the Agnéby River system [19.1 vs 5.5%; odds ratio (OR) 4.0, 95% confidence interval (CI) 3.1–5.1]. By contrast, *S. haematobium* prevalence was significantly higher in the Agnéby River system compared with the Mé River system (8.0 vs 5.2%) (OR 0.6, 95% CI 0.4–0.8). In the villages in the Mé River system, the prevalence of *S. mansoni* and *S. haematobium* were below 20% with the exception of three localities with higher prevalence, namely Apiadji, Diasson and Mafa Mafou.

Snail and prawn density and prevalence of human schistosomiasis

As shown in Fig. 5A and B, there was not a clear correlation in the density of prawns and intermediate host snails in relation to the prevalence of human schistosomiasis. Two groups of localities were identified: one group with a low prevalence of schistosomiasis (<10%) and another with a moderate prevalence of schistosomiasis (10–50%). Two villages in the Mé River system, Apiadji and Diasson, were additionally identified as high-prevalence spots with 82.4 and 56.9% prevalence, respectively (Fig. 5A). High densities of prawns were recorded in localities where there were no intermediate host snails, while there were no prawns in localities with a high abundance of intermediate host snails.

Discussion

Snail and prawn abundance

We aimed at elucidating the relationship between intermediate host snails and riverine prawns in two coastal river basins in south-eastern Côte d'Ivoire. The high abundance of two intermediate host snail species of schistosomiasis (i.e. *Bi. pfeifferi* and *Bu. globosus*) recorded in the Agnéby River system might be explained by hydrological features (permanent water), coupled with suitable microhabitats, such as shallow water, type of substrate and presence of aquatic plants (Betterton *et al.*, 1988; Utzinger and Tanner, 2000; Cecchi *et al.*, 2007). Of note, *Bi. pfeifferi* is a cosmopolitan species found in man-made habitats (e.g. irrigation systems and small multipurpose dams) and natural streams (Utzinger *et al.*, 1997; Utzinger and Tanner, 2000; Dida *et al.*, 2014; Diakité *et al.*, 2017). *Bulinus globosus* snails, on the other hand, show preferences for river environments with a vegetation cover. Our results are in line with observations made in the central part of Côte d'Ivoire (Gbocho *et al.*, 2015) and in Kenya (Opisa *et al.*, 2011). We speculate that the low abundance of *Bu. truncatus* is explained by unfavourable environmental conditions. In fact, this species shows habitat preferences for sunlit, clean aquatic environments that are not covered by vegetation,

Table 1. Infection with *Schistosoma mansoni* and *S. haematobium* in the study villages in the Agnéby and Mé River systems, stratified by the two population groups (9- to 12-year-old children and 20- to 55-year-old adults), surveyed

Village	<i>Schistosoma mansoni</i>			<i>Schistosoma haematobium</i>		
	Total (%)	School-aged children (%)	Adults (%)	Total (%)	School-aged children (%)	Adults (%)
Agnéby River system						
Anno	8/124 (6.5)	8/96 (8.2)	0/28 (0.0)	29/123 (23.6)	27/96 (28.1)	2/27 (7.4)
Armébé	1/140 (0.7)	1/92 (1.0)	0/48 (0.0)	1/136 (0.7)	1/88 (1.1)	0/48 (0.0)
Arragué	4/143 (2.8)	4/100 (4.0)	0/43 (0.0)	0/143 (0.0)	0/100 (0.0)	0/43 (0.0)
Attéhou	1/133 (0.8)	0/94 (0.0)	1/39 (2.6)	3/130 (2.3)	3/91 (3.3)	0/39 (0.0)
Attinguie	4/127 (3.1)	4/86 (4.6)	0/41 (0.0)	19/126 (15.1)	16/85 (18.8)	3/41 (7.3)
Ehouéguié	2/143 (1.4)	2/97 (2.1)	0/46 (0.0)	17/143 (11.9)	17/97 (17.5)	0/46 (0.0)
Gbéssé	16/144 (11.1)	7/95 (7.4)	9/49 (18.4)	1/143 (0.7)	1/95 (1.0)	0/48 (0.0)
M'Bonoua	8/124 (6.5)	4/96 (4.1)	4/28 (14.8)	14/124 (11.3)	14/96 (14.6)	0/28 (0.0)
M'Bourou	8/123 (6.5)	5/95 (5.3)	3/28 (10.7)	2/123 (1.6)	2/95 (2.1)	0/28 (0.0)
Offa	15/136 (11.0)	15/98 (15.1)	0/38 (0.0)	9/136 (6.6)	8/98 (8.2)	1/38 (2.6)
Offoriguie	24/146 (16.4)	11/100 (11.0)	13/46 (28.3)	10/146 (6.8)	9/100 (9.0)	1/46 (2.2)
Ottopé	4/122 (3.3)	4/96 (4.2)	0/26 (0.0)	9/122 (7.4)	8/96 (8.3)	1/26 (3.8)
Mé River system						
Adonkoi	9/132 (6.8)	8/100 (8.0)	1/32 (3.1)	5/132 (3.8)	5/100 (5.0)	0/32 (0.0)
Ahoutoué	0/146 (0.0)	0/100 (0.0)	0/46 (0.0)	9/142 (6.3)	6/100 (6.0)	3/42 (7.1)
Apiadji	122/148 (82.4)	82/97 (84.5)	40/51 (78.4)	1/148 (0.7)	1/97 (1.0)	0/51 (0.0)
Attiekoi	14/139 (10.1)	11/100 (11.0)	3/39 (7.7)	0/139 (0.0)	0/100 (0.0)	0/39 (0.0)
Diasson	74/130 (56.9)	65/100 (65.0)	9/30 (30.0)	34/129 (26.4)	34/100 (34.0)	0/29 (0.0)
Duquesne Cremone	0/122 (0.0)	0/100 (0.0)	0/22 (0.0)	3/121 (2.5)	2/100 (2.0)	1/21 (4.8)
Grand Akoudzin	1/135 (0.7)	0/96 (0.0)	1/39 (2.9)	25/133 (18.8)	15/94 (16.0)	10/39 (25.6)
IRHO La Mé	5/139 (3.6)	4/100 (5.0)	1/39 (2.6)	2/139 (1.4)	2/100 (2.0)	0/39 (0.0)
Lobo Akoudzin	4/143 (2.8)	1/100 (1.0)	3/43 (7.0)	1/139 (0.7)	1/97 (1.0)	0/42 (0.0)
Mafa Mafou	49/129 (38.0)	33/81 (40.7)	16/48 (33.3)	3/128 (2.3)	3/81 (3.7)	0/47 (0.0)
Yakassé Mé	6/119 (5.0)	6/100 (6.0)	0/19 (0.0)	1/119 (0.8)	1/100 (2.0)	0/19 (0.0)
Zodji	2/140 (1.4)	2/100 (2.0)	0/40 (0.0)	18/140 (12.9)	17/100 (17.0)	1/40 (2.5)
Total	381/3227 (11.8)	277/2319 (11.9)	104/908 (11.4)	216/3204 (6.8)	193/2306 (8.4)	23/898 (2.6)

such as dams and small man-made lakes (Brown, 1994). Environmental factors, which influence the rise and fall of freshwater snail populations, can differ from one habitat to another (Poda *et al.*, 2004).

The number of snail species recorded did not change much according to season, which might be explained by ambient water temperatures throughout the year. Indeed, temperature fluctuations in the southern part of Côte d'Ivoire are small, characteristic of dense tropical forest-type vegetation. Similar observations were made before in the same region (Da Costa *et al.*, 2000).

The number of prawn species recorded during our study is lower than that observed in previous studies in the Mé River (N'Zi *et al.*, 2003). *Desmocariss trispinosus* was the most abundant species, followed by *C. africana*. It is conceivable that the abundance of these two species is linked to their ecology, as both species tolerate low levels of dissolved oxygen and high amounts of organic matter (Cumberlidge, 2005). In natural environments, snails and prawns are exposed to environmental factors that influence their distribution, density and abundance. The pH and TDS seem to be the key determinants of *Bi. pfeifferi*, *Bu. globosus*,

C. africana and *C. nilotica* abundance. The association between the presence of intermediate host snails and pH range (6.4–7.2) in our study is consistent with observations from several other studies that revealed that these species proliferate in alkaline environments (Abdel Malek, 1958; Marie *et al.*, 2015). Our study results confirm that *C. africana* and *C. nilotica* are characteristic of aquatic environments where substrates consist of dead wood, leaves and rocks, and that are adapted to low dissolved oxygen content. The TDS content obtained in our study indicates good water quality, and hence, favourable minerals for the development of snails and prawns. Prawns of the genus *Caridina* and schistosomiasis intermediate host snails share the same ecological condition. The observed association might be explained by the relatively small *Caridina* prawns, hence they do not prey on intermediate host snails.

Surprisingly, predatory prawns of the *Macrobrachium* genus have been recorded at considerably lower abundance compared with previous investigations conducted in the Mé River (N'Zi *et al.*, 2003) and the Boubo River elsewhere in Côte d'Ivoire (N'Zi *et al.*, 2008). Indeed, the choice of sites was made on the basis of

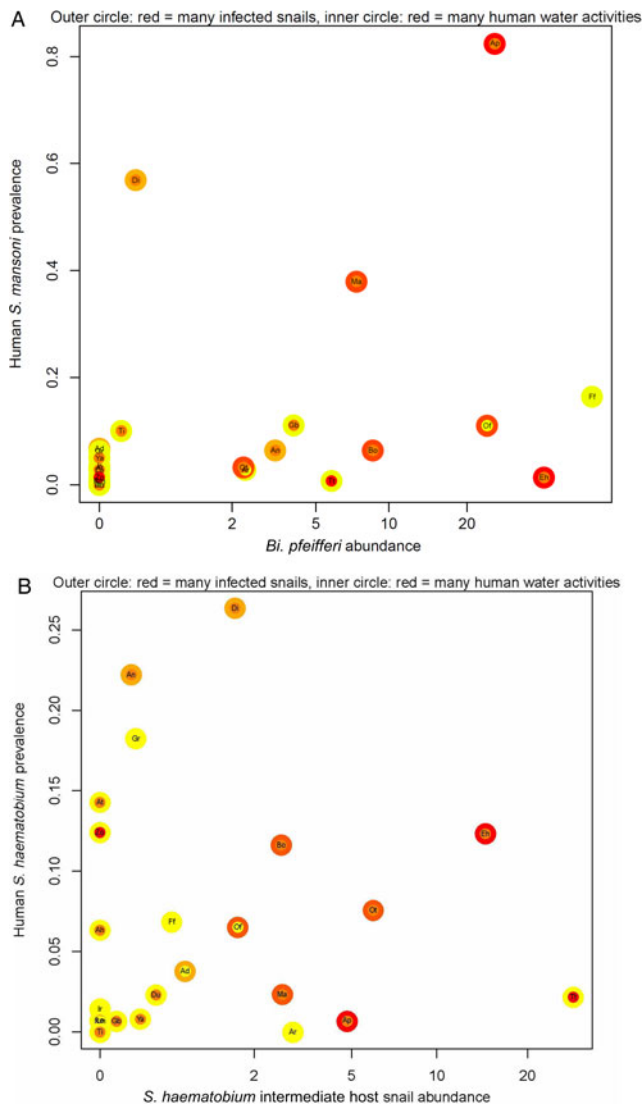


Fig. 5. (A) Relationship between *Biomphalaria pfeifferi* abundance and prevalence of *Schistosoma mansoni* infection among humans around the two coastal river systems Agnéby and Mé in Adzopé and Agboville in south-eastern Côte d'Ivoire. (B) Relationship between *Schistosoma haematobium* intermediate host snails and prevalence of *S. haematobium* infection among humans around the two coastal river systems Agnéby and Mé in Adzopé and Agboville in south-eastern Côte d'Ivoire.

previous studies that reported the presence of *Macrobrachium* prawns (N'Zi *et al.*, 2003). Several factors might explain the low abundance and absence of *Macrobrachium* in our study sites in the Mé and Agnéby River systems. First, in contrast to species belonging to the *Caridina* genus, which can tolerate conditions of low oxygenation, species of the *Macrobrachium* genus require relatively more oxygen for their development. This explains their presence in the main river courses with flow velocity of 1 m s^{-1} . Second, sampling was mostly carried out in human-water contact sites which are generally highly disrupted by human populations by mechanical means and the use of detergent, soap and other products. Therefore, the migration of these species in search of prey or favourable breeding place in salty or brackish environment at certain periods of the year may explain their absence.

On genera level, it was observed that *Macrobrachium* and *Desmocariss* were found in the same environment (main stream) and *Caridina* in the tributaries of each river system. Further studies should investigate the nutrition patterns of these species.

Taken together, our observations suggest that habitat preference of the predatory *Macrobrachium* prawns show little overlap with that of schistosomiasis intermediate host snails. Similar

conclusions were drawn by Camara *et al.* (2009), studying the ecology of prawns in the Banco national park in Abidjan. Although ecological preference seems the main reason identified for the minimal overlap of prawn and intermediate host snail populations in this study, we cannot entirely exclude predation by the prawns as an explanatory factor for the negative correlation found. However, more research will be needed to confirm any causal links.

Human schistosomiasis

The regions of Agnéby and Mé are endemic for both intestinal and urogenital schistosomiasis (Coulibaly *et al.*, 2011). Our results confirm the coexistence of the two blood flukes *S. mansoni* and *S. haematobium*. The villages surveyed are considered hypoendemic or mesoendemic, suggesting that the high abundance of intermediate host snails does not translate into high levels of cercarial shedding, as human infection levels are quite low. Similar results have been reported from Kenya and Uganda, where only very few snails were shedding cercariae, despite a high abundance of intermediate host snails (Standley *et al.*, 2010; Opisa *et al.*, 2011). Absence or low infection might be due to large-scale praziquantel treatments that were initiated in recent years through the national schistosomiasis control programme. However, some villages have been identified with high prevalence rates of *S. mansoni*, coupled with high or low abundance of intermediate host snails and no or few prawns.

Prawn and snail abundances in relation with schistosomiasis infection

Our study clearly demonstrates that there is a relationship between prawn and snail intermediate host abundance, both at the scale of the river system and the village. The Agnéby River system has many snail and few prawn populations, while the Mé River system exhibits many prawn and few snail populations. With regard to schistosome infection in both humans and snails, we have observed more infections in humans and snails in the Mé region, mainly caused by *S. mansoni*. This contradictory observation cannot be explained by the nature of schistosomiasis transmission which is focal; however, it is well established that the presence of snails does not necessarily lead to infection, human behaviour being one of the main determinants.

Concluding remarks

This study, conducted in two coastal river basins of south-eastern Côte d'Ivoire has shown that *Macrobrachium* prawns are present albeit at low abundance in the main river courses that are well oxygenated, while the intermediate host snails of schistosomiasis are mainly present in the secondary tributaries. Hence, predatory prawns and intermediate host snails do not share the same habitats. While the presence of intermediate host snails were positively correlated with TDS, pH and clear water, predatory prawns showed a positive relationship with redox potential, resistivity and clear water. Hence, environmental factors are clearly influential of this predator-prey system. At present, the study area is considered hypoendemic or mesoendemic for schistosomiasis, while the high abundance of intermediate host snails and the levels of cercariae infection do not correlate with human infection. However, there is high risk of schistosomiasis in some localities where very high prevalences of *S. mansoni* were recorded with high abundance of intermediate host snails and no or few prawns. In the two river systems assessed, our study indicates that there is a correlation between prawn and snail intermediate host abundance. However, it has yet to be demonstrated that there is

causation. No clear pattern was found between snail–prawn population density and human schistosomiasis.

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Conflict of interest. None.

Ethical standards. The study was approved by the national ethics committee of Côte d’Ivoire (reference no. 114/MSLS/CNER-dkn). Additionally, approval was obtained from local health and village authorities of Adzopé and Agboville. Village committees were informed about the objectives, procedures, and potential risks and benefits of the study. Written informed consent was obtained from adult participants and from parents/guardians of minors (aged <18 years).

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