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Effectiveness of a comprehensive schistosomiasis japonica control program in Jiangsu province, China, from 2005 to 2008

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ABSTRACT

The effectiveness of a comprehensive schistosomiasis japonica control program implemented in 8 villages along the Yangtze river in Jiangsu province from 2005 to 2008 was studied. Control measures included snail control, chemotherapy of humans and livestock, health education, and transmission cycle interruption using sanitation in dwellings and at anchorage sites for fishermen and sailors. The *Schistosoma japonicum* prevalence among residents and livestock, the total area of snail habitats, the *Oncomelania hupensis* snail density, and the percentage of infected snails served as indicators for the effectiveness of the control efforts. After 4 years of program implementation, the seroprevalence in humans had decreased from 9.03% to 3.24% ($P < 0.001$) and the parasitological prevalence among males had decreased from 0.42% to 0.12% ($P = 0.004$). Among females, it remained stable at a low level. The *S. japonicum* prevalence in livestock had decreased from 2.94% to 0% ($P < 0.001$). Additionally, the area where infected snails could be found had shrunk from 89.99 hectares (ha) to 16.00 ha, the snail density had decreased from 0.56 to 0.32 per 0.1 m^2, and the percentage of infected snails had dropped from 0.38% to 0.12% (all $P < 0.001$). The results demonstrate that an integrated schistosomiasis japonica control strategy focusing on the main transmission cycles and reservoirs and combines chemotherapy, infrastructure interventions and health education combined with robust surveillance is feasible and allows to effectively control *S. japonicum*.

1. Introduction

Schistosomiasis japonica is a zoonotic disease caused by the blood fluke *Schistosoma japonicum*. It is endemic in eastern Asia, including in the People's Republic of China (P.R. China). In this country, approximately 65 million individuals currently are at risk of infection (Zhou et al., 2007; Zhou et al., 2005) despite numerous government-initiated or – backed attempts at its control over the past five decades (Utzinger et al., 2005). Significant changes in key determinants of transmission and the termination of the World Bank Loan Project (WBLP) for schistosomiasis control in 2002 resulted in important shifts in disease endemicity and epidemiology in P.R. China (Chen et al., 2005; Wu et al., 2008; Wu et al., 2007b). Liang et al. (2006) described that both environmental and socioeconomic factors played an important role in the re-emergence of the disease. Today, schistosomiasis japonica mainly occurs in two distinct environmental zones in P.R. China, namely the marshland and lakes region in eastern and central China, and hilly and mountainous regions in Sichuan and Yunnan provinces (Zhou et al., 2005). Currently, more than 80% of all human *S. japonicum* cases in P.R. China are concentrated in the marshland and lakes regions of Hunan, Hubei, Jiangxi, Anhui and Jiangsu provinces where the interruption of transmission has proved particularly difficult to achieve (Hao et al., 2006; Utzinger et al., 2005).

Jiangsu province is located on the lower reaches of the Yangtze river in East China. Historically, Jiangsu province suffered from a very high prevalence of schistosomiasis japonica but as a result of a control strategy focusing on the elimination of the intermediate host snail *Oncomelania hupensis*, in 1976 the province reached the criteria for transmission control, i.e. an infection rate among residents and livestock of less than 1% and the absence of infected snails over two years of surveillance. No acute cases were reported

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from 1978 to 1984 (Wang et al., 2008; Yuan et al., 2005). Following repeated flooding by the Yangtze river in the 1990s, acute human schistosomiasis cases were seen again and the area inhabited by infected *O. hupensis* started to increase (Li et al., 2009; Wu et al., 2008; Yuan et al., 2000). In 2004, *S. japonicum* was endemic in 35 counties in Jiangsu province and 39 acute cases were reported (Yang et al., 2005).

In 2004, the Ministry of Health of P.R. China announced a new comprehensive *S. japonicum* control strategy focusing on the management and elimination of the main transmission cycles and reservoirs. The National Office for Schistosomiasis Control selected 5 pilot sites in the marshland and lakes region to test the new strategy, which proved highly effective (Wang et al., 2008; Wang et al., 2009; Wu et al., 2007b).

In 2005, the Jiangsu provincial government announced both medium- and long-term goals for schistosomiasis control with programs based on the blueprint of the national strategy. Particularly emphasized were snail control, chemotherapy of both infected humans and livestock, health education and the targeted interruption of transmission cycles through environmental and behavioral modification, and improved sanitation. Here, we report the key results pertaining to the effectiveness of the measures adopted in Jiangsu province in 8 pilot villages with different *S. japonicum* prevalence levels.

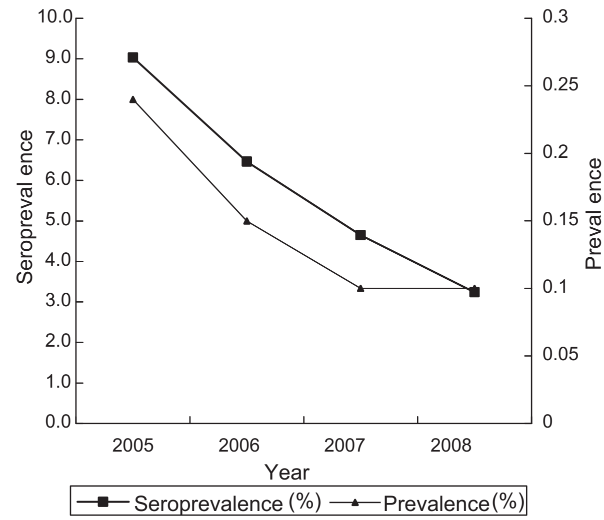

Fig. 1. Evolution of the average *S. japonicum* seroprevalence and parasitological prevalence in humans in the study villages from 2005 to 2008.

2. Materials and methods

2.1. Study area

The 8 villages included in the pilot program were selected considering the following characteristics: location along the Yangtze river, different *S. japonicum* endemicity levels, ecology of snail habitats, resident population and economic situation. The considered variables along with their respective values in each village are presented in Table 1. In all study villages, water contact primarily resulted from fishing, washing clothes and swimming (Sun et al., 2008).

The study was approved by the institutional review boards of the National Institute of Parasitic Diseases, China CDC (Shanghai, P.R. China) and the Jiangsu Institute of Parasitic Diseases (Wuxi, P.R. China).

2.2. Snail control

From 2005 to 2008, twice-yearly (spring and autumn) snail surveys were carried out along the river banks and in marshland and ditches around the villages. A stratified random sampling scheme was employed to select survey locations whereby the endemic village represented the first stratum and the type of snail habitat represented the second stratum. A snail collection device made of steel wire and consisting of a 0.1 m^2 square frame was placed every 30 m along the survey line. All snails within the frame were collected, enumerated, crushed and microscopically examined to detect larval *S. japonicum*. Molluscicide using niclosamide was carried out in all areas where snails had been found. Annually, between 549.59 ha and 948.72 ha of snail habitat were treated with molluscicide. Environmental modification such as constructing fish ponds, digging new ditches and filling of infested ones was also carried out in certain areas. Over the study period, 389.31 ha of snail habitat underwent environmental modification.

2.3. Chemotherapy

Each year, about 90% of all individuals aged 6–60 years were screened for schistosomiasis japonica antibodies using an indirect hemagglutination assay (IHA) (Jia et al., 2009). One stool samples was collected from seropositive individuals, and 3 Kato–Katz thick smear slides were prepared from each sample and examined microscopically. Egg counts were not established, and no intestinal helminth eggs were diagnosed (Zhang et al., 2009). Seropositives were given a single dose of praziquantel (dosage: 40 mg/kg body weight) except those who had been found to excrete eggs; the latter were given a two day course of praziquantel at 60 mg/kg body weight.

All cattle were examined annually using the egg hatch test (Zhang et al., 2009). Infected livestock and livestock from pastures where the presence of snails had been confirmed were treated with a single dose of praziquantel at a dosage of 20 mg/kg body weight.

Table 1
Baseline characteristics of the 8 villages included in a pilot program for schistosomiasis control in Jiangsu province, P.R. China, in 2005.

Name	Endemic type	Prevalence level*	Snail habitat (ha)	Population	Farmland (ha)	Households with tap water (%)	Households with sanitary lavatories (%)	Annual per-capita income (RMB*)
Qili	Marshland	1–5%	104.33	1600	209.87	100.00	86.1	4000
Xinzhou	Marshland	<1%	380.65	1556	162.48	100.00	100	1500
Yangjiawan	Water-network	<1%	218.32	1816	132.69	100.00	0.0	4600
Pushu	Water-network	No new cases	0.55	1651	109.00	89.19	1.3	5600
Sanzhou	Marshland	1–5%	41.20	1316	132.69	74.95	12.9	3450
Changjiang	Marshland	<1%	43.26	1608	189.63	100.00	86.0	8216
Yanjiang	Marshland	1–5%	596.70	1944	98.17	82.45	11.6	6726
Shicheng	Marshland	<1%	16.43	1616	73.79	100.00	100	5628

* RMB is the abbreviation of the currency unit of P.R. China, namely the Chinese Yuan.

2.4. Interruption of transmission cycles through health education and sanitation

Health education interventions targeting all local residents and aiming at modifying local residents' behavior, most importantly reducing the frequency of exposure to infective water, and enhancing participation in screening and treatment were implemented three times a year. Cartoons, videotapes, comic-style booklets and other media were employed to disseminate knowledge about risks, symptoms and options for the prevention of schistosomiasis japonica.

Sanitary lavatories and tap water were provided to all local residents' households. Containers for the collection of feces on ships were handed out to fishermen and sailors, and sanitary public toilets were built at landing sites.

3. Results

3.1. S. japonicum infections in humans and livestock

S. japonicum prevalences in humans from 2005 to 2008 are displayed in Tables 2–5, stratified by village, occupation, sex and age. Each year, between 7075 and 9016 people were screened; translating into a total of 32,852 person-years over the entire study period or more than 90% of the eligible population. The seroprevalence continuously decreased from 9.0% to 3.2% over the study period (χ^2 = 293.84, P < 0.001; Table 2; Fig. 1.). From 2005 to 2008, the seroprevalence of 10.0% in males and 8.1% in females decreased to 3.9% (χ^2 = 135.44, P < 0.001) and 2.6% (χ^2 = 197.20, P < 0.001) respectively (Table 3). Among all strata, the highest seroprevalence was found among fishermen and sailors. Their specific prevalence decreased from 22.9% and 18.7% in 2005 to 10.0% and 6.8% in 2008 respectively (χ^2 = 53.84, χ^2 = 62.82, P < 0.001; Table 4).

Between 2005 and 2008, a total of 1868 stool examinations were performed, and 48 individuals were parasitologically confirmed to be infected with *S. japonicum*. The prevalence of egg-positive individuals in the study villages steadily but non-significantly decreased from 0.2% in 2005 to 0.1% in 2008 (χ^2 = 7.735, P = 0.052). While the prevalence among males decreased significantly from 0.4% in 2005 to 0.1% in 2008 (χ^2 = 8.159, P = 0.004), it fluctuated between 0% and 0.1% (P > 0.05) among females. In 2005, the highest prevalence was found among those aged 30–39 years (0.3%) but in 2008, the highest prevalence (0.3%) was found among those more than 50 years but less than 60 years old (Table 5).

A total of 729 heads of livestock or more than 90% of the livestock population of each village were screened for *S. japonicum* infection over the study period. Infected livestock were only found in Sanzhou village where the recorded annual prevalences were 6.5%, 14.3%, 4.4%, and 0% (χ^2 < 15.93, P < 0.001) from 2005 to 2008 (Table 6).

Between 2005 and 2008, a total of 1926 humans and 41 animals were treated with praziquantel.

3.2. S. japonicum infections in snails

From 2005 to 2008, the percentage of confirmed snail habitats out of all field survey sites was 28.2%, 19.2%, 14.2% and 14.2% respectively. The total area of snail habitats was reduced from 667.79 ha in 2005 to 352.76 ha in 2008 (Table 7). The area where infected snails were found decreased from 89.99 ha to 16.00 ha over the study period, and the snail density decreased from 0.56/0.1 m^2 to 0.32/0.1 m^2. The density of infected snails was 0.00213/0.1 m^2 in 2005 and 0.00038/0.1 m^2 in 2008 (Table 8). In 2008, schistosome-infected snails were only found in Sanzhou and Yanjiang village. The prevalence of schistosome infections among the snails col-

Table 2
Annual number of serum and stool examinations and derived prevalence of schistosomiasis japonica in the 8 villages included in a pilot control program in Jiangsu province, P.R. China, from 2005 to 2008.

Name of study village	2005				2006				2007				2008			
	No of sero-examinations	No of stool examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	No of stool examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	No of stool examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	No of stool examinations	Sero-prevalence (%)	Prevalence (%)
Qiji	1430	203	14.2	0.1	1176	138	12.5	0.4	1048	75	8.3	0	1194	81	7.4	0
Xinzhou	947	111	11.72	0.1	858	116	13.5	0	766	82	10.7	0	868	52	6.0	0
Yangjiawan	1023	147	14.37	0	997	40	4.0	0	801	22	2.7	0	1032	28	2.7	0
Pushu	1085	22	2.0	0	1101	9	0.8	0	918	4	0.4	0	2020	7	0.4	0
Sanzhou	1039	77	7.4	1.1	986	60	6.1	0.7	805	33	4.1	0.37	903	28	3.1	1
Changjiang	1070	32	3.0	0	934	17	1.8	0	979	17	1.7	0	907	16	1.8	0
Yanjiang	1030	156	16.6	0.7	1027	116	12.3	0.1	922	82	8.9	0.43	1005	65	6.9	0
Shicheng	1037	19	1.8	0	1021	8	0.8	0	836	2	0.2	0	1087	3	0.3	0
Total	8661	767	9.0	0.2	8100	504	6.5	0.1	7075	317	4.6	0.1	9016	280	3.2	0.1

Table 3
Prevalence of schistosomiasis japonica in the 8 villages included in a pilot control program in Jiangsu province, P.R. China, from 2005 to 2008, stratified by sex.

	2005			2006			2007			2008		
	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Preval-ence (%)
Male	4168	10.0	0.4	3879	8.0	0.3	397	6.1	0.2	4420	3.9	0.1
Female	4493	8.1	0.1	4221	5.0	0.0	3678	3.3	0	4596	2.6	0.1
Total	8661	9.0	0.2	8100	6.5	0.1	7075	4.6	0.1	9016	3.2	0.1

Table 4
Prevalence of schistosomiasis japonica in the 8 villages included in a pilot control program in Jiangsu province, P.R. China, from 2005 to 2008, stratified by occupation.

Occupations	2005			2006			2007			2008		
	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Preval-ence (%)
Farmer	5682	9.6	0.2	5560	6.9	0.2	4533	5.1	0.1	6184	3.2	0.1
Fisherman	437	22.9	0.7	374	21.1	0.3	391	13.0	0.8	462	10.0	0
Sailor	209	18.7	1.9	127	12.6	0	161	6.8	0.6	146	6.8	0
Migrant worker	426	4.5	0.2	363	2.7	0	307	2.6	0	359	2.5	0.6
Housewife	79	6.3	0	129	2.3	0	4	0	0	121	0.8	0
Infant (<12years)	46	8.7	0	44	4.5	0	24	0	0	26	0	0
Student	1121	3.2	0.1	1135	1.8	0.1	1183	1.8	0	1229	1.2	0
Others	661	4.7	0.0	368	2.4	0	472	1.3	0	489	2.5	0.0
Total	8661	9.0	0.2	8100	6.5	0.1	7075	4.6	0.1	9016	3.2	0.1

lected between 2005 and 2008 was 0.38%, 0.67%, 0.37% and 0.12% respectively (χ^2 = 39.6, P < 0.001).

4. Discussion

In 2005, the government of Jiangsu province revised the schistosomiasis control strategy to emphasize once again integrated measures aimed at reducing the transmission of *S. japonicum*. The results of the pilot intervention presented here show that most villages indeed reached the criteria of transmission control after the main sources of infection had been identified and effective control measures had been employed. The human seroprevalence declined by 64.1% and the parasitological prevalence by 57.5% during the study period (2005–2008). In 2008, positive stool tests were only reported from one village. Similarly, the area where infected snails were found decreased by 82.2%. However, there clearly remains a potential for re-emergence of the disease in the study area as snail habitats with uninfected snails, infected snails and human infections continued to be found in at least some of the study locations. This probably indicates that the employed control measures were powerful with regard to reducing the prevalence of schistosome infections in humans and animals as well as the area where snails could be found but failed to deliver the ultimate push for local elimination, at least within the limited time of project implementation. The notion of a powerful yet not all-inclusive toolbox for control is also underscored by the observation that the parasitological prevalence among females was barely affected by the control program.

A number of observations are offered for discussion here. First, most villages indeed reached the criteria of transmission control after the control measures had been employed, and the control measures were effective at different prevalence level. In the 3 villages with a baseline prevalence level of 1–5%, the average seroprevalence dropped from 12.89% to 5.99% and the parasitological prevalence dropped from 0.56% to 0.29%. In the 4 villages with a baseline prevalence of less than 1%, the parasitological prevalence was 0% during the study period, suggesting that the control measures were effective in both medium- and low-endemicity environments.

Second, the percentage of infected snails among the total number of snails, the density of infected snails and the area of snail habitats where infected snails were found decreased, further underscoring the effectiveness of the control approach. However, progress was not uniform and the snail habitat even increased over the program duration in certain villages (Sanzhou and Yanjiang), probably due to the inherent dynamics of wetlands (e.g. floods) and uneven implementation of the control measures.

Third, fishermen and sailors are high-risk population subgroups for both morbidity and schistosome transmission in Jiangsu province, underlined by consistently higher sero- and parasitological prevalences among these groups compared to other occupations, probably explained by their more intensive and prolonged exposure to the waters along the Yangtze river where most snail habitats are located. Their mobility makes regular interventions such as periodic chemotherapy and health education particularly difficult (Ross et al., 1997). As they often travel between endemic areas, there also is a risk that they act as carriers, re-introducing schistosomes into areas from which the parasite had been eliminated. In the case of the mobile populations in Jiangsu, heavily endemic regions in Jiangxi and Anhui province further upstream the Yangtze river are of particular concern. A specific control strategy for these two high-risk groups was devised with an aim to minimize exposure and break the cycle of transmission, apparently with some success. The relative prominence of migrant workers among those infected with schistosomes in 2008

Table 5
Prevalence of schistosomiasis japonica in the 8 villages included in a pilot control program in Jiangsu province, P.R. China, from 2005 to 2008, stratified by age.

Age group	2005			2006			2007			2008		
	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)	No of sero-examinations	Sero-prevalence (%)	Prevalence (%)
6-	223	2.7	0	239	1.3	0	179	1.1	0	185	0	0
10-	1090	3.2	0.2	1019	2.4	0.1	1011	1.3	0	1013	0.8	0
20-	670	6.0	0.3	505	5.3	0	546	2.9	0	622	1.9	0
30-	1412	9.7	0.3	1254	7.7	0.2	1171	4.5	0.2	1297	3.2	0.1
40-	1693	10.1	0.1	1746	7.4	0.3	1797	5.7	0.2	2063	4.1	0
50-	1705	13.4	0.2	1703	8.5	0.1	1753	6.2	0.1	2051	3.8	0.3
60-	1868	8.8	0.3	1634	6.0	0.1	618	5.3	0.2	1785	3.8	0.2
Total	8661	9.0	0.2	8100	6.5	0.1	7075	4.6	0.1	9016	3.2	0.1

Table 6
Prevalence of schistosomiasis japonica in cattle in the 8 villages included in a pilot control program in Jiangsu province, P.R. China, from 2005 to 2008.

Name of study village	2005		2006		2007		2008	
	No of sero-examinations	Prevalence (%)	No of sero-examinations	Prevalence (%)	No of sero-examinations	Prevalence (%)	No of sero-examinations	Prevalence (%)
Qili	0	–	28	0	30	0	30	0
Xinzhou	31	0	34	0	0	–	0	–
Yangjiawan	63	0	36	0	62	0	0	–
Pushu	0	–	0	–	0	–	0	–
Sanzhou	108	6.5	35	14.3	45	4.4	6	0
Changjiang	8	0	0	–	0	–	0	–
Yanjiang	28	0	32	0	82	0	60	0
Shicheng	0	–	0	–	0	–	0	–

Table 7
Oncomelania hupensis snail habitats in the 8 villages included in a pilot control program in Jiangsu village, P.R. China, from 2005 to 2008 (ha).

Village	2005		2006		2007		2008	
	Snail habitat	Infected snail habitat	Snail habitat	Infected snail habitat	Snail habitat	Infected snail habitat	Snail habitat	Infected snail habitat
Qili	104.32	71.52	86.08	71.52	54.54	39.98	86.08	0.00
Xinzhou	245.62	1.00	84.54	0.00	7.54	0.00	7.54	0.00
Yangjiawan	5.30	0.00	5.30	0.00	0.00	0.00	6.00	0.00
Pushu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sanzhou	22.00	11.00	26.00	25.50	29.50	22.00	26.50	14.00
Changjiang	20.20	0.00	0.00	0.00	0.00	0.00	0.48	0.00
Yanjiang	253.92	6.47	223.92	8.00	223.92	8.00	209.73	2.00
Shicheng	16.43	0.00	16.43	0.00	16.43	6.01	16.43	0.00
Total	667.79	89.99	442.27	105.02	331.93	75.99	352.76	16.00

Table 8
Density of *Oncomelania hupensis* snails and infected snails in the 8 villages included in a pilot control program in Jiangsu village, P.R. China, from 2005 to 2008 (/0.1 m^2).

Village	2005			2006			2007			2008		
	No. of frames	Live snails	Infected snails	No. of frames	Live snails	Infected snails	No. of frames	Live snails	Infected snails	No. of frames	Live snails	Infected snails
Qili	1910	1.40	0.01309	3256	0.47	0.00645	2479	0.42	0.00161	1025	0.39	0.00000
Xinzhou	10,032	0.18	0.00010	10,027	0.01	0.00000	5413	0.01	0.00000	5760	0.01	0.00000
Yangjiawan	3425	0.05	0.00000	2945	0.01	0.00000	2871	0.00	0.00000	3077	0.01	0.00000
Pushu	1071	0.00	0.00000	1154	0.00	0.00000	2673	0.00	0.00000	747	0.00	0.00000
Sanzhou	2228	4.22	0.01750	3935	2.60	0.02414	3595	3.18	0.01725	3742	0.86	0.00214
Changjiang	5179	0.04	0.00000	5039	0.00	0.00000	5039	0.00	0.00000	4427	0.01	0.00000
Yanjiang	6759	0.38	0.00010	8231	0.87	0.00170	9669	0.77	0.00052	9254	0.59	0.00032
Shicheng	415	1.27	0.00000	429	0.54	0.00000	1239	0.16	0.00242	1283	0.08	0.00000
Total	31,019	0.56	0.00213	35,016	0.55	0.00371	32,978	0.61	0.00224	29,315	0.32	0.00038

further underscores the problems associated with migration from other endemic areas and the resulting challenges with regard to the implementation of comprehensive curative and preventive schistosomiasis control measures.

Fourth, livestock such as cattle and buffaloes historically were important drivers of the local epidemiology of schistosomiasis in P.R. China (Wang et al., 2005; Yuan, 1993). Starting in the 1990s, the economy of Jiangsu province rapidly developed, and the number of cattle decreased significantly. Additionally, grazing in snail habitats was actively discouraged or outlawed and it has already been reported that livestock did not constitute an important source of infection anymore in the province (Wu et al., 2007a; Zhao et al., 2005). This was confirmed in the present study where it was found that the *S. japonicum* prevalence among livestock was already low at the onset the control program, with infected livestock only found in one village. At program completion, no infections were observed in any livestock population.

We conclude that an integrated *S. japonicum* control strategy emphasizing the interruption of the transmission cycle through snail control, environmental and behavioral modification and sanitation, complemented by praziquantel treatment of humans and livestock, is feasible and effective once the main reservoirs and sources of infection have been identified. The strategy employed in Jiangsu province could probably also be implemented in other endemic areas in P.R. China with comparable ecological, cultural and socio-economic characteristics. The required financial input and institutional capacity for implementation probably precludes similar control activities in certain countries unless massive international aid is available. Of note, the persistence of snails in its natural habitats emphasizes once again the need for sustained surveillance and timely shifts in the control strategy to mitigate the risk of re-emergence of the parasite.

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