Parasitology International 57 (2008) 271–276

Contents lists available at ScienceDirect

Parasitology International

journal homepage: www.elsevier.com/locate/parint

Effect of floods on the transmission of schistosomiasis in the Yangtze River valley, People's Republic of China

Xiao-Hua Wu [a], Shi-Qing Zhang [b], Xing-Jian Xu [c], Yi-Xin Huang [d], Peter Steinmann [e], Jürg Utzinger [e], Tian-Ping Wang [b], Jing Xu [a], Jiang Zheng [a], Xiao-Nong Zhou [a,*]

[a] National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention, 200025 Shanghai, People's Republic of China
[b] Anhui Institute of Parasitic Diseases, 241000 Wuhu, People's Republic of China
[c] Hubei Institute of Parasitic Diseases, 430070 Wuhan, People's Republic of China
[d] Jiangsu Institute of Parasitic Diseases, 214064 Wuxi, People's Republic of China
[e] Department of Public Health and Epidemiology, Swiss Tropical Institute, CH-4002 Basel, Switzerland

ARTICLE INFO

Available online 8 April 2008

Keywords:
Schistosomiasis japonica
Flood
Snail dispersal
Infection
People's Republic of China

ABSTRACT

The aim of the present study was to assess the effect of floods on the transmission of schistosomiasis in the Yangtze River valley, People's Republic of China. Retrospective analyses of malacologic, clinical and epidemiologic data, covering a 22-year period, were carried out to elucidate the dispersal patterns of intermediate host snails (*Oncomelania hupensis*), and acute and chronic infections with *Schistosoma japonicum* in humans in relation to floods. Potential *O. hupensis* habitats in years with floods were 2.6–2.7 times larger than in years when water levels were normal. Both the density and infection rate of *O. hupensis* dropped in the first two years after a flood, but significantly increased in the third year. The number of acute cases with schistosomiasis japonica was markedly higher in years characterized by floods; on average, 2.8 times more cases were observed when compared to years that the Yangtze River had normal water levels. In view of our findings, emergency responses are warranted as soon as possible after the occurrence of a flood in order to avoid or mitigate the reemergence and spread of human schistosomiasis in the People's Republic of China.

1. Introduction

Schistosomiasis is a water-based, chronic and poverty-promoting disease, caused by an infection with blood flukes of the genus *Schistosoma* [1,2]. The distribution and intensity of schistosome infections are closely linked to behavioral, climatic, ecologic and socioeconomic factors [1,3–6]. In the People's Republic of China, *S. japonicum* is endemic and occurs along the Yangtze River and in mountainous areas of the Sichuan and Yunnan provinces [7,8]. The Yangtze River valley is prone to floods, which in turn can impact schistosomiasis negatively [9]. In the face of ecologic transformations at local and regional scales and global warming [10,11], patterns of floods are likely to change and the frequency and extent of floods might augment [12]. In the Dongting Lake region in the middle reaches of the Yangtze River, for example, the frequency of massive floods surged from 14 events between 1931 and 1990 (i.e. a flooding event once every 4–5 years), to five events between 1990 and 1999 (i.e. a flooding event approximately once every second year) [13].

Floods in the Yangtze River are accompanied with the spread of *Oncomelania hupensis*, the intermediate host snail of *S. japonicum*, thus facilitating the re-establishment of snail colonies in areas from where they had been previously eliminated. Floods are therefore a major impediment for the control and local elimination of schistosomiasis in the People's Republic of China and elsewhere [7,14]. Data collected during routine surveillance suggest that the prevalence of *S. japonicum* infection in humans increased in some parts where the transmission of the disease had been controlled, accompanied by high numbers of acute cases of schistosomiasis [15]. Since the early 1990s, it appears that the transmission patterns of *S. japonicum* in the Yangtze River valley have been influenced by major floods. As a result of the spread of *O. hupensis*, which is a key factor in the local transmission of schistosomiasis, further progress in the control of the disease has been hampered [14,16].

The objective of the present study was to investigate the potential impact of floods on local transmission patterns of schistosomiasis in the middle and lower reaches of the Yangtze River. We utilized retrospective data covering a 22-year period commencing in 1979. The data were obtained from annual reports issued by local and central authorities, and are based on malacologic surveys, as well as clinical and epidemiologic investigations in hospitals and community-based surveys.

* Corresponding author. Tel.: +86 21 6473 8058; fax: +86 21 6433 2670.
E-mail address: ipdzhouxn@sh163.net (X.N. Zhou).

1383-5769/$ – see front matter
doi:10.1016/j.parint.2008.04.004

2. Materials and methods

2.1. Study area

We focused on selected areas in the middle and lower reaches of the Yangtze River. Administratively, these areas are located in the provinces of Anhui, Hubei and Jiangsu, and they are particularly prone to major floods as seen in 1998, when the People's Republic of China experienced one of the worst floods in the last century.

Retrospective clinical, epidemiologic and malacologic data, covering the period from 1979 to 2000, were reviewed in order to further our understanding of the influence of floods on the dispersal of intermediate host snails and human infection patterns.

2.2. Dynamics of O. hupensis snail distribution

Annual data on intermediate host snail distribution (i.e. the total area inhabited by *O. hupensis*, including areas where *O. hupensis* habitats had been eliminated before but where snails have been found in an annual survey, and areas where snails have been newly discovered) were obtained from annual reports of the schistosomiasis control stations in Anhui province.

For the period of 1979 to 2000, hydrologic data for Anhui province were obtained from the National Bureau of Statistics of China (http://www.stats.gov.cn), the China Water Science Info Network (http://www.chinawater.net.cn) and the Anhui Provincial Water Resources Bureau [17]. Data were stratified into (i) normal (water levels similar to long-term average), (ii) flood, and (iii) drought (water level considerably below long-term average). Snail distribution patterns and their relationship with hydrologic conditions were investigated.

Additionally, a series of experiments were carried out with the objective to deepen our understanding of the impact of the 1998 flood on the dispersal and proportion of infected snails. A systematic snail sampling survey was carried out in flooded villages of the Anhui province, following routine procedures put forward by the Ministry of Health [18]. For the appraisal of snail infection rates, carried out after the 1998 flood in the lower reaches of the Yangtze River in Jiangsu province, a standard sampling approach was utilized [18]. In brief, snails were collected in the survey areas and dissected under a microscope in order to establish their infection status. The proportion of sampling frames (covering a surface area of 0.1 m^2) in which living and/or infected snails were identified was calculated, and the respective snail density and snail infection rates estimated.

2.3. Snail dispersal patterns

The dispersal patterns of *O. hupensis* during and after a flood were studied during field surveys and the information obtained complemented with experimental observations. Field surveys were carried out in Yangxin county, Hubei province in order to investigate the spread of snails in relation to flood-related events, i.e. breakdown of embankments, flood-diversion, water-logging, and flooding inside and outside embankments. Moreover, the dispersal of *O. hupensis* was studied in the lower valley of the Yangtze River in Jiangsu province. For this purpose, drifting material (e.g. grass, weeds branches, etc.) on the water surface was collected at specific sampling locations and time points over the course of the highest water levels (June to October) in the years 2002 and 2003. Snails attached to the surface area of drifting material were collected and their numbers, stratified by juvenile and adult specimens, were recorded for each sampling time point. The number of snails per unit weight of floating material was estimated and their infection status assessed under a microscope, as described before.

2.4. Acute cases of S. japonicum and infection prevalence in local residents

Acute schistosomiasis, also known as Katayama syndrome, refers to a systemic hypersensitivity reaction that can be triggered by high quantities of antigens released by migrating schistosomula. It usually occurs within 2–12 weeks following primary infection or heavy re-infection. Whilst the onset of Katayama syndrome is sudden, symptoms are rather unspecific (e.g. fever, headache, general malaise and tiredness) [19]. The annual number of acute cases of schistosomiasis japonica in the period of 1979 to 2000 was obtained from readily available reports from the schistosomiasis control stations in Anhui province. These data were linked to the hydrologic conditions, and the database was explored for the relationship between floods and number of acute schistosomiasis cases.

Epidemiologic investigations were carried out in two natural villages (a natural village is a spatial accumulation of houses within an administrative village) inside Fengyi islet in Zongyang county, Anhui province. The two natural villages were considered non-endemic for schistosomiasis prior to the 1998 flood. Due to the flood, the embankment broke down in the Fengyi islet. The prevalence of *S. japonicum* among local residents, aged 5–65 years, was assessed by means of fecal examination using the Kato-Katz technique [20]. The relationship between snail distribution and prevalence data was examined.

3. Results

3.1. Snail distribution in relation to floods

Table 1 shows that the distribution of *O. hupensis*-inhabited areas varied from one year to another. The percentage of habitats where *O. hupensis* had been eliminated previously, but where snails re-emerged due to floods, ranged from 0.4% to 5.8%. Newly discovered snail-infested areas accounted for up to 10.1% of the total snail habitats. In years with normal water levels, the average annual re-emerging areas and new snail-infested areas were 258.0 ha and 322.7 ha,

Table 1
Flood situation of the Yangtze River, snail distribution and number of cases with acute schistosomiasis from 1979 to 2000 in Anhui province, People's Republic of China

Year	Hydrologic condition	Total snail habitats (ha)	Re-emerging snail habitats		New snail habitats		No. of cases with acute schistosomiasis (% of total)
			Area (ha)	% of total	Area (ha)	% of total	
1979	Normal	22,872.9	84.5	0.4	526.7	2.3	176 (1.3)
1980	Flood	24,742.6	338.4	1.4	2503.2	10.1	543 (4.0)
1981	Normal	24,815.8	558.2	2.3	442.9	1.8	274 (2.0)
1982	Flood	24,209.8	397.6	1.6	132.2	0.6	372 (2.7)
1983	Flood	23,379.1	194.0	0.8	394.1	1.7	392 (2.9)
1984	Flood	24,065.9	1213.6	5.0	818.1	3.4	492 (3.6)
1985	Normal	23,109.5	121.9	0.5	74.1	0.3	225 (1.6)
1986	Normal	21,581.2	173.6	0.8	55.6	0.3	260 (1.9)
1987	Normal	21,269.7	171.9	0.8	565.9	2.7	667 (4.9)
1988	Drought	21,697.2	251.0	1.2	969.3	4.5	321 (2.3)
1989	Flood	22,495.9	802.2	3.6	788.5	3.5	4664 (34.1)
1990	Drought	24,703.6	1309.1	5.3	1290.6	5.2	1725 (12.6)
1991	Flood	28,775.3	1667.6	5.8	2722.1	9.5	999 (7.3)
1992	Flood	28,857.4	292.9	1.0	351.2	1.2	427 (3.1)
1993	Normal	28,721.3	193.3	0.7	157.5	0.6	320 (2.3)
1994	Drought	28,523.0	225.4	0.8	439.6	1.5	553 (4.0)
1995	Normal	28,804.9	505.3	1.8	436.8	1.5	341 (2.5)
1996	Flood	27,483.1	289.9	1.1	312.6	1.1	172 (1.3)
1997	Normal	27,912.8	255.6	0.9	322.4	1.2	114 (0.8)
1998	Flood	28,351.4	830.0	2.9	453.7	1.6	240 (1.8)
1999	Flood	26,631.1	583.8	2.2	216.5	0.8	118 (0.9)
2000	Drought	29,011.2	351.4	1.2	91.1	0.3	294 (2.1)

Table 2
Spread of *O. hupensis* into potentially new habitats after the 1998 flood in Yangxin county, Hubei province, stratified by flood outcomes

Flood outcome	Snail-infested area as a result of flooding (ha)	Percentage
Embankment breakdown	72.0	39.0
Flooding inside the embankment	44.3	24.0
Flooding outside the embankment	35.1	19.0
Flood diversion	19.9	10.8
Water-logging	13.1	7.1
Total	184.4	100

respectively. Significantly higher average annual re-emerging areas (661.0 ha), and new snail-infested areas (869.2 ha) were found in years characterized by floods. Hence, the re-emerging and new snail-infested areas in flood years were, on average, 2.6 and 2.7 times larger than in years with normal hydrologic conditions.

3.2. Snail dispersal patterns

Individual floods influenced the dispersal of snails in different ways, as revealed by malacologic surveys and experimental observations. Detailed field surveys following the 1998 flood showed that the expansion of snail-infested areas in Yangxin county, Hubei province occurred in all different types of micro-environments, although at different levels. As summarized in Table 2, the increases due to the breakdown of (i) embankments, (ii) flood-diversion, (iii) water-logging, and flooding (iv) inside and (v) outside of embankment accounted for 39.0%, 24.1%, 19.0%, 10.8% and 7.1%, respectively.

Results from snail counts on different floating material collected in the Yangtze River at different sampling time points in the period between June and October in the years 2002 and 2003 are summarized in Table 3. In 2002, 55 kg of floating material was examined, which revealed 683 *O. hupensis* snails the majority of which were adult specimens (90.9%). Hence, on average, 12.4 *O. hupensis* snails were collected per kg of floating material. In the subsequent year, a total of 86.5 kg floating material was recovered with a total of 3846 snails identified, of which 76.4% were adult specimens. On average, 44.5 snails were identified per kg of floating material; hence about 3.6 times more than in the preceding year. The highest snail density on floating material was noted in August.

Table 3
Number of snails adhering to floating material collected in the lower reaches of the Yangtze River, Jiangsu province, at different collection time points between June and October in the years 2002 and 2003

Date	Floating material examined (kg)	No. of snails collected			Average no. of snails collected per kg of floating material
		Juvenile	Adult	Total	
2002					
28 June	5.0	0	11	11	2.2
12 July	7.5	17	99	116	15.5
27 July	7.0	5	59	64	9.1
11 August	9.0	29	248	277	30.8
26 August	9.0	11	76	87	9.7
9 September	14.0	0	116	116	8.3
24 September	3.5	0	12	12	3.4
Total	55.0	62	621	683	12.4
2003					
17 June	0.5	0	0	0	0
2 July	18.5	0	0	0	0
17 July	13.0	87	30	117	9.0
31 July	14.0	151	59	210	15.0
15 August	7.0	583	562	1145	163.6
30 August	7.0	79	1408	1487	212.4
14 September	10.0	6	534	540	54.0
28 September	12.5	0	333	333	26.6
13 October	4.0	0	14	14	3.5
Total	86.5	906	2940	3846	44.5

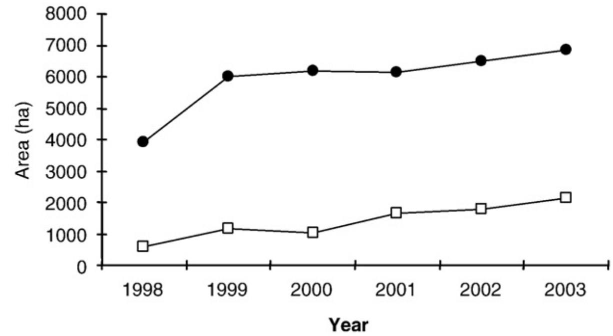

Fig. 1. Annual fluctuations of snail-infested areas (●) and areas where infected snail were found (□) after the 1998 flood in the marshlands along the lower reaches of the Yangtze River.

3.3. Effect of the 1998 flood

To investigate local setting-specific and temporal effects of the 1998 flood on snail dispersal, the 431 flooded villages in the Anhui province were stratified as follows: (i) 225 villages (52.2%) located in hilly regions; (ii) 71 villages (16.5%) situated in lake regions; (iii) 66 villages (15.3%) located in islet settings; and (iv) remaining 69 villages (16.0%) located in river beach regions. According to national criteria for the control and elimination of schistosomiasis in the People's Republic of China [21], in 332 villages (77.0%), schistosomiasis was still endemic when the 1998 flood occurred, whereas in 82 villages (19.0%) schistosomiasis transmission had been controlled, and interrupted in 17 villages (3.9%). Following the 1998 flood, the local area of snail-infested habitats increased by 5.0%. The highest increase was noted in the hilly regions (+55.4%), then in the islet regions (+37.4%), whereas in the lake regions and on river beaches only marginal increases were noted, 4.9% and 2.3%, respectively. In areas where transmission had been interrupted previously, the snail areas increased by almost two-thirds, whereas in areas where the transmission was classified as under control, a significantly lower increase of 10.5% was noted. In these 431 villages, there were a total of 718 sites with established snail colonies prior to the flood. After the flooding had occurred, the number of sites with infested snails increased by 23.0%. The highest increase was observed in those settings where schistosomiasis was still endemic (+44.7%).

Spatially-explicit analysis of snail dispersal following the 1998 flood revealed that *O. hupensis* spread longitudinally to the lower

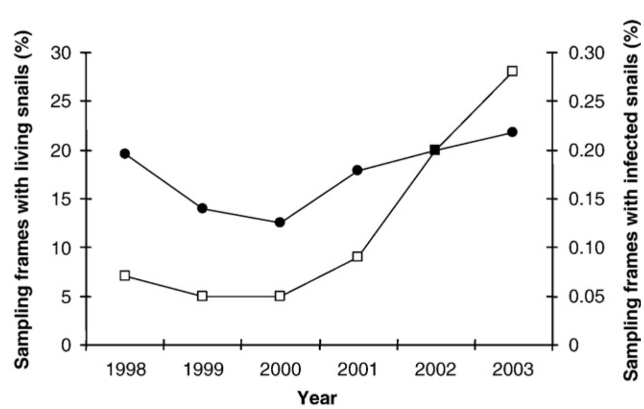

Fig. 2. Annual fluctuations of the frequency of sampling frames where living snails were found (●) and where infected snails were found (□) after the 1998 flood in the marshlands along the lower reaches of the Yangtze River.

reaches of the Yangtze River in the Jiangsu province. Snail-infested areas in the marshlands increased, on average, by 11.8% annually from 1998 to 2003, resulting in a total expansion of the snail areas by a factor of 1.75 within these five years. Habitats where infected snails were detected increased, on average, by 29.6% each year over the same period, hence resulting in a total expansion of snail-positive areas by a factor of 3.6. We found a significant correlation between the total snail-infested area and the area inhabited by infected snails in the period 1998–2003 (r=0.84, P<0.05) (Fig. 1). After an initial decrease, the proportion of snail sampling frames where living and infected snails were found (r=0.93, P<0.01) (Fig. 2), as well as the proportion and density of infected snails showed a steady increase following the flooding event (r=0.83, P<0.01). The final peak was noted in 2003 (Fig. 3).

3.4. Acute cases of schistosomiasis japonica

According to annual reports from the schistosomiasis control stations in Anhui province, there were a total of 13,689 cases of acute schistosomiasis japonica between 1979 and 2000. Among these 22 survey years, 10 were considered flood years and four classified as drought years, whereas the remaining eight were considered years with normal water flows in the Yangtze River. Overall, 8419 cases of acute schistosomiasis japonica were recorded in the designated flood years, and hence the average annual number of acute cases in flood years was 842. The largest number of acute schistosomiasis japonica cases was observed in the flood year of 1989; there were 4646 cases, accounting for more than one-third of all the acute cases recorded in the 22-year observation period analyzed here. In the four drought years, there were 2893 cases of acute schistosomiasis japonica, accounting for an average of 723 cases per year. The remaining 2377 cases were observed in normal years (on average 297 cases per year). The average number of acute schistosomiasis cases recorded in flood years was therefore 2.8 times higher than in years when there was no, or very little, flooding.

3.5. Human infection prevalence in local residents

As a result of the 1998 flood, the embankment protecting the Fengyi islet in Anhui province collapsed. Subsequently, snails spread to the villages inside the islet. There were six administrative villages inside the islet, among which only one was previously considered non-endemic for schistosomiasis. Repeated malacologic surveys carried out in two natural villages in the non-endemic administrative village (i.e. Hongqi and Xiyi natural villages), found a considerable number of sampling frames positive for *O. hupensis*; 5.5%, 21.6%, 61.1% and 8.0% in the years 1999, 2000, 2001 and 2002, respectively. The densities of *O. hupensis* were 0.19, 1.06, 3.75 and 0.38 per 0.1 m^2 in the four years following the flooding event, respectively. Schistosome-

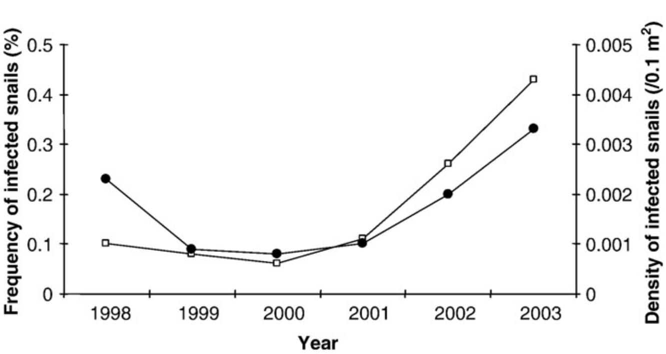

Fig. 3. Annual fluctuations of frequency of infected snails (●) and density of infected snails (□) after the 1998 flood in the marshlands along the lower reaches of the Yangtze River.

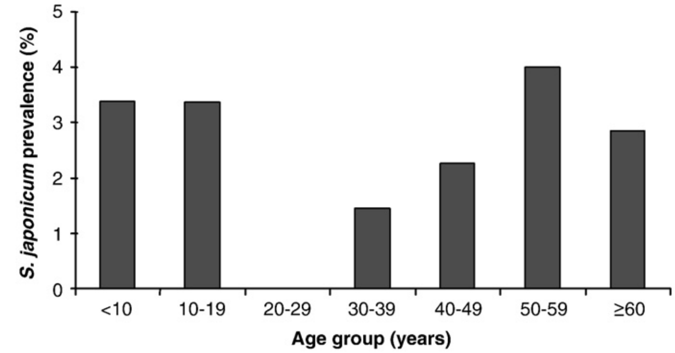

Fig. 4. Human infection prevalence of *S. japonicum* in different age groups in Fengyi islet, Anhui province, in 2002.

positive snails were found in 2000, 2001 and 2002. The highest density of infected *O. hupensis* snails was recorded in 2001; it was 0.047 snails per 0.1 m^2.

The first cases of schistosomiasis were noted in 2002 and a community-based survey in that year revealed an infection prevalence among residents aged 5–65 years of 3.0%. Age-stratification showed that children and teenagers (<19 years) and adults aged 50–60 years had considerably higher infection prevalence than the other age groups (Fig. 4). The infection prevalence among males was significantly higher than among females (5.3% versus 1.2%; χ^2=7.95, P<0.01).

4. Discussion

Floods can transform entire landscapes, and hence flooding events have far-reaching ecologic, public health and socioeconomic consequences. There is considerable concern that the frequency of floods and the extreme events of flooding will increase in the face of global warming [12,22]. With regard to public health, the issue investigated in the current study was how floods might influence the transmission of schistosomiasis in selected areas along the middle and lower reaches of the Yangtze River. Floods facilitate the dispersal of intermediate host snails and can therefore spread schistosomiasis by exposing individuals to infected freshwater bodies [1,13,23–28]. Indeed, we found that in the 10 designated flood years that occurred between 1979 and 2000 in the Yangtze River valley, on average, the areas of re-emerging and newly discovered snail habitats were 2.6–2.7 times larger than in years with normal river discharges.

Moreover, the catastrophic flood that occurred in 1998 along the Yangtze River had a cascade of negative health impacts, including enhanced transmission dynamics of schistosomiasis japonica across the three provinces of the lake region. For example, the flood promoted the establishment of new snail populations in areas where *O. hupensis* had not been endemic previously [27,28]. The dispersal of *O. hupensis* also led to the re-establishment of snail populations in settings from where they had been eliminated [27].

In the current study, we identified the collapse of embankments and the flooding of marshlands as the main drivers for dispersal of *O. hupensis*. For example, the areas inhabited by snails and habitats where infected snails could be found in the riverbank ecozones of the Jiangsu province increased by 1936.5 ha (+44.7%) and 599.5 ha (+105.1%), respectively [25]. It is also important to note that the marshlands of the lake regions are among the remaining 'hot spots' for transmission of schistosomiasis in the People's Republic of China, to a large extent explained by the important contribution of water buffaloes in the transmission of the disease [29–31].

The breakdown of embankments represents a major impediment for the further progress on schistosomiasis control. Once embankments are destroyed, snails can colonize these previously protected areas. For example, in the riverbank zone of the Jiangsu province, in the period of 1998 to 2003, the snail-infested area and the surface of habitats where infected snails could be found increased by 11.8% and 29.3%, respectively. Importantly though, the density of snails, and particularly the density of infected snails, normally decline rapidly after the occurrence of floods. Hence, different snail surveillance indices (e.g. proportion of sampling frames positive for living and infected snails, the snail infection rates and the density of infected snails) decreased within the first two years of the 1998 flood, but increased in the third year. Post-flood malacologic surveys in the Poyang Lake region indicated that the reproduction of *O. hupensis* was inhibited during the floods but gained in prominence one year later [27]. One reason for this is that the development of snail eggs are negatively affected by being submerged over prolonged periods during a flood, which results in a decrease of snails densities and a decline in snail dispersal [32,33]. It is thus conceivable that post-flood investigations of potential snail habitats carried out immediately after the recession of the floodwater do not reliably recognize the local establishment of snails, since densities might be below detecting a critical threshold. Additionally, the establishment of *S. japonicum*-infected snail populations usually lags behind the colonization of an area, possibly due to the lower densities of the snail population and cercariae population in the flood areas. Previous research has linked snail dispersal to factors such as the flow of water, duration of the flooding, water quality, catastrophic events such as collapse of embankments, vicinity of current snail habitats and geographic as well as environmental characteristics of flooded areas [28]. Hence, only monitoring the presence of snails and their infection rates are insufficient snail control measures. It is essential to recognize and address the full scope of the issues mentioned above for the efficient management of snail populations after the occurrence of floods.

Floods impact on current human behavior and water exposure vary depending on the stage of the flood cycle, the severity and duration of the flood, catastrophic events like embankment breakdown, among other. In the People's Republic of China, considerable numbers of people are dispatched to fight floods, exposing many immunologically-naïve individuals with reference to schistosomiasis to great risk. In 1998, for example, the number of flood-relieve workers exceeded 1.5 million in the Poyang Lake area alone [34]. The breakdown of embankments and the subsequent flooding of vast areas exposed eight million residents to the Yangtze flood water in 1998 [35]. The frequency of water contact also increased due to individual emergency actions to safe personal belongings, crops and livestock, as well as temporary economic opportunities such as catching fish and other aquatic products in the flooded areas. In the absence of preventive measures, an increase of the number of acute schistosomiasis cases can be expected and this is also what we found (240 cases of acute schistosomiasis in 1998 versus 114 cases in the preceding year). However, it should be noted that many of the flood-relieve workers were given oral artemether or artesunate shortly before and 1–2 weeks after they got in contact with potentially infested water, which prevented the development of patent *S. japonicum* infections [36,37].

Another major factor for outbreaks of acute schistosomiasis is the drifting of cercariae to new sites, including areas where people are not aware of the risk of water exposure or, for some reason, unable to take protective measures [26]. This is most probably the explanation for remarkable changes in the geographic distribution of acute cases following floods, including outbreaks of acute schistosomiasis in low-endemic areas, places where schistosomiasis had been previously eliminated [38,39]. It has also been noted that during floods, water contact related to daily activities replaced the traditional occupational risk factors for acute schistosomiasis [23]. Immediately after the 1998 floods, the infection rates, both of humans and livestock, as well as the number of acute cases were remarkably higher than before in the five provinces of the lake region along the Yangtze River [24,33,40]. Of note, the prevalence significantly increased in the flood-recession period which can be attributed to the time lag between the actual infection and the detectability of infection, i.e. the prepatent period.

5. Conclusion

Although the 1998 flood disaster led to the dispersal of snails and a short-term increase in the number of acute cases of schistosomiasis and the human prevalence, the long-term epidemic situation of the disease could be kept at a stable and low level due to the deployment of effective control measures. The experience of the 1998 flood event led to the articulation of a set of recommendations for the successful implementation of schistosomiasis control in the wake of floods. Firstly, collaboration with meteorologic agencies for reliable flood prediction and warning should be strengthened to allow the preparation of adequate resources for infection prevention and control. This recommendation is of particular salience in the face of climate change that might considerably impact the frequency and transmission dynamics of schistosomiasis in the People's Republic of China [11]. Secondly, high-risk population should be identified based on flood prediction and historical experience, and provision and distribution of equipment for individual protection (e.g. rubber boots) and chemoprophylactic drugs (e.g. artemether and artesunate) should be made avaiable [36,37]. Thirdly, health education, including sound information and communication on effective protection from infection in emergency situations should be implemented regularly, but especially during emergency situations. Fourthly, the surveillance of schistosomiasis should be strengthened during and after flood events in order to detect an outbreak of acute schistosomiasis as well as new snail habitats, and to implement measures for the control of human schistosomiasis and newly established transmission sites while they are still contained. Fifthly, environmental management and integrated control should be enhanced [7,14]. Namely, the collaboration between the regional program for schistosomiasis control, disaster control units and agencies dealing with public health and the hydrologic as well as agricultural development and management of the region should be strengthened and mutual use of means and facilities encouraged.

Acknowledgements

We thank our colleagues from the provincial institutes of parasitic diseases in Anhui, Hubei and Jiangsu for their help during field research activities and data collection. This project received financial support from the Ministry of Science and Technology (grant no. 2001BA705B08, 2004BA718B12), the UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR) (grant no. A30298), and the Key Laboratory of Parasite and Vector Biology of the Ministry of Health, China. P. Steinmann and J. Utzinger are grateful to the Swiss National Science Foundation for financial support (project no. PPOOB-102883 and PPOOB-119129).

References

[1] Steinmann P, Keiser J, Bos R, Tanner M, Utzinger J. Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk. Lancet Infect Dis 2006;6:411–25.
[2] King CH, Dangerfield-Cha M. The unacknowledged impact of chronic schistosomiasis. Chronic Illn 2008;4:65–79.
[3] Huang YX, Manderson L. The social and economic context and determinants of schistosomiasis japonica. Acta Trop 2005;96:223–31.
[4] Gryseels B, Polman K, Clerinx J, Kestens L. Human schistosomiasis. Lancet 2006;368:1106–18.
[5] Liang S, Seto EYW, Remais JV, Zhong B, Yang CH, Hubbard A, et al. Environmental effects on parasitic disease transmission exemplified by schistosomiasis in western China. Proc Natl Acad Sci U S A 2007;104:7110–5.
[6] Li YS, Raso G, Zhao ZY, He YK, Ellis MK, McManus DP. Large water management projects and schistosomiasis control, Dongting Lake region, China. Emerg Infect Dis 2007;13:973–9.

[7] Utzinger J, Zhou XN, Chen MG, Bergquist R. Conquering schistosomiasis in China: the long march. Acta Trop 2005;96:69–96.
[8] Zhou XN, Guo JG, Wu XH, Jiang QW, Zheng J, Dang H, et al. Epidemiology of schistosomiasis in the People's Republic of China, 2004. Emerg Infect Dis 2007;13:1470–6.
[9] Zhou XN, Lin DD, Yang HM, Chen HG, Sun LP, Yang GJ, et al. Use of Landsat TM satellite surveillance data to measure the impact of the 1998 flood on snail intermediate host dispersal in the lower Yangtze River basin. Acta Trop 2002;82:199–205.
[10] Yang GJ, Vounatsou P, Zhou XN, Tanner M, Utzinger J. A potential impact of climate change and water resource development on the transmission of *Schistosoma japonicum* in China. Parassitologia 2005;47:127–34.
[11] Zhou XN, Yang GJ, Yang K, Wang XH, Hong QB, Sun LP, et al. Potential impact of climate change on schistosomiasis transmission in China. Am J Trop Med Hyg 2008;78:188–94.
[12] McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet 2006;367:859–69.
[13] Li JB, Zhu X, Zhou GH, Cai BH. The compound effect of disastrous floods in Dongting Lake on concurrence of ecological disasters. Acta Ecol Sin 2002;22:334–40.
[14] Zhou XN, Wang LY, Chen MG, Wu XH, Jiang QW, Chen XY, et al. The public health significance and control of schistosomiasis in China — then and now. Acta Trop 2005;96:97–105.
[15] Wang RB, Wang TP, Wang LY, Guo JG, Yu Q, Xu J, et al. Study on the re-emerging situation of schistosomiasis epidemics in areas already under control and interruption. Chin J Epidemiol 2004;25:564–7.
[16] Chen XY. The challenges and strategies in schistosomiasis control program in China. Acta Trop 2002;82:279–82.
[17] Anhui Provincial Water Resources Bureau. Flood and Drought Disasters in Anhui Province. Beijing: China Water Power Press; 1998.
[18] Ministry of Health. The Handbook for Schistosomiais Control. Shanghai: Shanghai Scientific and Technologic Press; 2000.
[19] Ross AG, Vickers D, Olds GR, Shah SM, McManus DP. Katayama syndrome. Lancet Infect Dis 2007;7:218–24.
[20] Katz N, Chaves A, Pellegrino J. A simple device for quantitative stool thick-smear technique in schistosomiasis mansoni. Rev Inst Med Trop Sao Paulo 1972;14:397–400.
[21] Ministry of Health. National Criteria for Control and Elimination of Schistosomiasis in China. Beijing: Office of Endemic Diseases Control, China Publishing House for Criteria; 1996.
[22] Diaz JH. The influence of global warming on natural disasters and their public health outcomes. Am J Disaster Med 2007;2:33–42.
[23] Pan XP, Wang Z, Cheng LC. Analysis on the outbreak of acute schistosomiasis by flood. Chin J Schisto Control 1998;10:122–3.
[24] Chen W, Yang XX, Huang XB, Zhang YH, Cai SX, Liu JB, et al. The influence of flood disaster on schistosomiasis transmission in 1998. Chin J Schisto Control 2000;12:202–5.
[25] Huang YX, Rong GR, Cai G, Gao ZH, Zhou XN, Zhu YC. Effects of flood on snail distribution in marshland along Yangtze River in Jiangsu province. Chin J Schisto Control 2000;12:346–9.
[26] Xiao JW, Tian ZY, Qu GS, Yao XM, Liu DS, Zhu YC, et al. Analysis on the outbreak of acute schistosomiasis in the period of flood. Chin J Schisto Control 2000;12:231.
[27] Chen HG, Lin DD, Zhang SJ, Hu F, Ning A, Ceng XJ, et al. Studies on the influence of flood disaster on schistosomiasis transmission and on its control in Poyang Lake region. I. Analysis of schistosomiasis prevalence in flood year and following year. Chin J Schisto Control 2001;13:141–6.
[28] Li WJ, Tan HZ, Yang MX, Zhou YB, Tang GM, Yun CY, et al. Analysis on the changes of snail status of schistosomiasis before and after embankment collapsed in Dongting Lake region. J Chin Physician 2002;4:837–40.
[29] Wang TP, Johansen MV, Zhang SQ, Wang FF, Wu WD, Zhang GH, et al. Transmission of *Schistosoma japonicum* by humans and domestic animals in the Yangtze River valley, Anhui province, China. Acta Trop 2005;96:198–204.
[30] Guo JG, Li YS, Gray D, Ning A, Hu GG, Chen HG, et al. A drug-based intervention study on the importance of buffaloes for human *Schistosoma japonicum* infection around Poyang Lake, People's Republic of China. Am J Trop Med Hyg 2006;74:335–41.
[31] Wu XH, Wang XH, Utzinger J, Kun Y, Kristensen TK, Bergquist R, et al. Spatio-temporal correlation between human and bovine schistosomiasis in China: insight from three nationwide surveys. Geospatial Health 2007;2:75–84.
[32] Yu DB, Xia QB, Xiao RW, Liang YS, Tan PP. Effect of flooding in spring on the development of *Oncomelania* eggs. Chin J Schisto Control 1995;7:134–7.
[33] Zheng YJ, Zhong JH, Chen XL, Lin DD, Zhao GM, Zhang SJ, et al. Influence of drowning on survival of *Oncomelania*. Chin J Schisto Control 2002;14:46–9.
[34] Zhang SJ, Lin DD, Hu F. Past and present of schistosomiasis in Poyang Lake area in China — the review of achievement on schistosomiasis control 50 years after the building of P.R. China. Chin J Schisto Control 1999;11:196–8.
[35] Guo JP. Progress of schistosomiasis control in 1998. Chin J Schisto Control 1999;11:129–31.
[36] Xiao SH, Booth M, Tanner M. The prophylactic effects of artemether against *Schistosoma japonicum* infections. Parasitol Today 2000;16:122–6.
[37] Utzinger J, Xiao SH, N'Goran EK, Bergquist R, Tanner M. The potential of artemether for the control of schistosomiasis. Int J Parasitol 2001;31:1549–62.
[38] Cao JH, Lei SX. Investigation on snail diffusion and hazard evaluation at large and middle city in Hubei province. Chin J Schisto Control 1991;3:174–5.
[39] Yao WD, Zhan T. Analysis on the outbreak of acute schistosomiasis at the interrupted areas in Dangtu county, Anhui province. J Practical Parasitol 1999;7:132.
[40] Li T, Yu BG, Dai YH. Impact and countermeasures on acute schistosomiasis transmission by Yangtze River flood. Chin J Schisto Control 2000;12:268–72.