Schistosoma japonicum infected sentinel mice surveillance and spatial point pattern analysis in Hubei province, China, 2010-2018

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Research Article

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Abstract

Background

Progress in national schistosomiasis control in China has successfully reduced disease transmission in many districts. However, a low transmission rate hinders conventional snail surveys in identifying areas at risk. In this study, *Schistosoma japonicum* infected sentinel mice surveillance was conducted to identify high risk areas of schistosomiasis transmission in Hubei province, China.

Methods

The risk of schistosomiasis transmission was assessed using sentinel mice monitoring in Hubei province from 2010 to 2018. Field detections were carried out in June and September and the sentinel mice were kept for approximately 35 days in a laboratory. Then they were dissected to determine whether schistosome infection was present. Ripley's K-function and kernel density estimation were applied to analyze the spatial distribution and positive point pattern of schistosomiasis transmission.

Results

A total of 190 sentinel mouse surveillance sites were selected to detect areas of schistosomiasis infection from 2010 to 2018, with 29 sites showing infected mice (15.26%).A total of 4723 mice were dissected and112 infected mice containing 256 adult worms were detected. The infection rate was 2.37% and an average of 2.28 worms was detected per infected mouse. Significantly more infected mice were detected in June samples than in September samples (x^2 = 12.11, P< 0.01).Ripley's L(d) index analysis showed that, when distance was less than or equal to 34.52 km, the sentinel mice infection pattern showed aggregation, with the strongest aggregation occurring at 7.86 km. Three hotspots were detected using kernel density estimation, namely: at the junction of Jingzhou District, Gong'an County and Shashi District in Jingzhou City; in Wuhan city at the border of the Huangpi and Dongxihu Districts and in the Hanan and Caidian Districts.

Conclusion

The results showed sentinel mice surveillance was useful in identifying high-risk areas and could provide valuable information for schistosomiasis prevention and control, especially concerning areas along the Yangtze River such as the Fu-Lun, Dongjing-Tongshun and Juzhang River basins.

Background

Schistosomiasis is a water-borne helminthic disease affecting both humans and animals, ranked second to malaria in causing long-term chronic human morbidity. The disease decreases both the growth and intellectual development of children and the production and working capacity of adults, affecting 200 million people in approximately 76 countries across Asia, Africa, and South America. Schistosomiasis caused by *Schistosoma japonicum* (*S. japonicum*) is widely endemic along the middle and lower reaches of the Yangtze River in China [1]. *Oncomelania hupensis* (*O. hupensis*), the only intermediate host of *S. japonicum*, plays a vital role in *S. japonicum* transmission in China. The distribution of *O.hupensis* largely depends on environmental conditions such as water level, soil type, vegetation coverage, temperature, and sunlight [2]. The schistosomiasis-endemic areas in China can be divided into three types: lake and marshland regions, plain regions with networks, and hilly and mountainous regions, according to the complex ecological features of *O.hupensis* and the geographical features of endemic areas [3].

Over the past six decades, Hubei province has made remarkable progress in reducing *S. japonicum* infections in humans through a combination of chemotherapy and snail control.The goal of reducing human and bovine infection prevalence below 1% in every endemic region by 2013 was achieved [4]. On that occasion, the schistosomiasis control program shifted its focus from transmission control to the elimination of the disease [5]., Schistosomiasis has historically been highly endemic in Hubei Province, which is located in the middle and lower reaches of the Yangtze River [6, 7]. The number of patients and cattle affected, and the relevant snail areas, have almost always been higher than in other schistosomiasis-endemic provinces in China [8].The *O.hupensis* in Hubei province are mainly distributed from the Yichang to the Wuxue segment of the Yangtze River, in the Jianghan Plain, and in the Hanbei, the Fushui, and other rivers connected to the Yangtze River. There are also several important water conservancy projects in the territory of Hubei province. The Three Gorges Project is world famous and its relationship with the distribution of downstream *O.hupensis* has also been extensively studied [9, 10]. The South-to-North Water Diversion Project is a major strategic project to alleviate water shortages and the deterioration of the ecological environment in the north [11]. The middle route of the project, from the Danjiangkou to Beijing, has caused the water level of the Han River to drop due to the diversion of Han River water sources. To compensate for the loss of water sources in the Han River, Yangtze River water has been diverted to the Han River in the "Water Diversion Works from the Yangtze River to the Hanjiang River" (WDWYH) project.

In China, schistosomiasis surveillance began in the middle of the 20th century after the founding of the People's Republic. The prevalence of schistosomiasis in humans, livestock, and *Oncomelania* snails was surveyed, and the results have provided a reliable basis for the treatment and control of this disease[12].The first schistosomiasis-specific surveillance system was introduced into China in the late 1980s, and a national schistosomiasis surveillance network was formally implemented in the early 1990s, following an initiative and cooperation of the World Bank Loan Project for schistosomiasis control[13]. Accordingly, both fixed (longitudinal) and flexible (horizontal) endemic surveillance sites were set up throughout China. These widespread and flexible monitoring sites have played a key role in elucidating variable trends in schistosomiasis endemicity. Schistosomiasis presents several surveillance challenges as shown in previous studies. First, the disease is mainly concentrated in rural areas where health and communication infrastructure is limited. Second, the clinical presentation of the disease is rarely acute and, like many chronic diseases, long-term infections can evade clinical detection and eventually lead to severe health sequelae later in life. Thus, reliance on passive surveillance can grossly underestimate the number of infections.

In 2014, the State Council of China issued a National Medium and Long-Term Plan for the Prevention and Control of Schistosomiasis (2004–2015), setting out schistosomiasis transmission control criteria and aiming for control to be achieved by 2015[14]. Accordingly, a document titled “Mid- and Long-term Plan on the Prevention and Control of Schistosomiasis in Hubei Province (2005–2015)” was also formulated. Strategy focused on control of infection sources, which represented a shift from the earlier strategy of morbidity control, to reduce the transmission of *S. japonicum* from humans and livestock to snails[15]. Under the policy guidelines, the schistosomiasis control strategy included the following main interventions: the replacement of bovines with tractors for agricultural activities, forbidding livestock to pasture in marshlands where snail habitats exist, environmental modification in high-risk areas with *O.hupensis*, recycling excreta to produce methane for cooking, requiring fishermen and boatmen to use containers to prevent excreta from being released into the waterways, and implementing other routine control measures, such as snail surveys and eradication, regular surveys and treatments, and health education[14].

After implementation of the plan in Hubei province, the areas with previously high susceptibility for schistosomiasis were significantly reduced. By 2013, the schistosomiasis infection prevalence rates among humans and livestock in Hubei province had reached the transmission control criterion of < 1%. Although this outcome indicates success in using the surveillance and control measures, low schistosomiasis endemicity now makes it difficult to identify high-risk areas using conventional surveillance methods such as *O.hupensis* snail surveys and wild animal fecal analyses. Rapid evaluation of water bodies and up-to-date risk information is an absolute requirement in low-endemic areas[16–18]. To address this issue, a monitoring and early warning method was employed for detecting schistosomiasis-endemic risk in key water regions in Hubei province. We used an early warning system involving data obtained concerning the exposure of sentinel mice to water in areas under surveillance along with spatial data monitored through a geographic information system (GIS) platform combined with a Global Positioning System (GPS). Ripley's K function analysis and kernel density estimation are important tools for detecting spatial point distribution patterns, and are more effective than classical statistical analysis in public health and epidemiological research fields [19–21]. Ripley's K function analysis can explore the spatial distribution pattern and aggregation pattern of cases at any scale and reflect the real distribution characteristics of cases at a more detailed level[22].Kernel density estimation then allows for a further analysis of the spatial distribution of case hot spots, and the results can be visualized[23]. In this study, schistosomiasis-endemic areas were monitored using sentinel mice in Hubei province from 2010 to 2018. The spatial pattern distribution characteristics of infected sentinel mice in Hubei province were analyzed using spatial methods to detect the hot spots and risk factors of infection, to provide suggestions for improved prevention and control measures.

Materials And Methods

Animal model

Kunming strain mice weighing 25g±3g were purchased from the Hubei Provincial Centre for Disease Control and Prevention. (Wuhan, China).
All procedures were designed by National Institute of parasitic diseases, Chinese Center for Disease Control and Prevention, and approved by the Committee or

Method and Procedures

Following the springtime *O.hupensis* snail survey, we implemented a schistosomiasis transmission surveillance method based on the use of sentinel mice in suspected high-risk water regions. Our main aim was to identify surveillance sites (i.e., areas used by both humans and livestock) that were positive for infected sentinel mice as quickly as possible while simultaneously recording data on local residents, livestock, snails, and wild animal fecal samples. Through this approach, we aimed to prevent both humans and livestock from becoming infected with schistosomiasis and supplement the routine schistosomiasis surveillance system.

Prior to initiating field work, on-site local staff at both the county and township levels participated in unified training courses conducted by the Hubei Institute of Schistosomiasis Prevention and Control (HISPC). This training aimed to ensure that the adopted plan, timing, approach, and norms were uniformly devised and implemented to ensure the accuracy and reliability of the experiment results. The trained field staff supervised the process of on-site surveillance to guarantee that as few sentinel mice as possible were unexpectedly lost. Mice were housed in a specific pathogen-free (SPF) laboratory and dissected in a medical morphological laboratory by a specialized team from the HISPC. Sentinel mouse monitoring was conducted as follows:

A). We selected the sentinel surveillance sites according to the following standards:

(1) an identification of *O. hupensis* within the last 5 years;

(2) frequent activity involving bovines or local residents in areas known to support *O. hupensis*;

(3) environments near neighborhoods or distribution centers used by boat fishermen (including the rivers connected to the Yangtze River that are areas known to support *O. hupensis*);

(4) large agricultural operation areas irrigated with reservoirs carrying *O. hupensis*;

(5) waters adjacent to national or provincial surveillance points.

B). Sentinel mice comprised males with body weights of 25g ± 3 g. Cylindroid wire-mesh cages were purchased from the HISPC. Each cage measured 51.3 cm in length, with a diameter of 11.1 cm, and was fitted with six spherical plastic foam balls tied to each side to float the cage on a water surface. Each cage was divided into five cells of equal size. Two cages were set at each site at a spacing interval of 10–20 m. Each cage contained two mice per cell (10 mice in total), and the cage position was adjusted to ensure that the tail and abdomen of each mouse would be exposed to the water. Sentinel surveillance was conducted from May to July and from September to October. The sentinel mice in the cages were exposed to the water surface from 10:00 a.m. to 14:00 p.m. on two consecutive days. The activities of the local residents and livestock, air and water temperatures, and flow velocity were recorded simultaneously.

C). The surviving mice were collected after exposure, marked, and returned to the animal facility, which was maintained at an appropriate ambient temperature (23–26ºC) and humidity (40–70%) for 35–40 days to allow the infective schistosomes to mature sufficiently. Subsequently, the mice were sacrificed and dissected, and the livers and portal/mesenteric veins were screened for *S. japonicum* eggs and adult worms, respectively. Mice that harbored eggs in the liver and/or adult worms in the portal and mesenteric veins were considered positive for schistosomiasis infection.

D). Data management, presentation, and electronic distribution were supported using Google Earth software (version 7.0), and photos of the sentinel surveillance field environments were recorded using Picasa (version 3.1). For each site, a database was established to include information about the location (latitude and longitude) and surveillance results. The field photographical images and sentinel mouse data from all sites were compiled via Google Earth Pro v7.1.8.3036 software and ArcGIS 10.5 software. The interval between dissection and data import was no longer than 7 days.

E). When positive results were found, a detailed plan for schistosomiasis control was established and set in motion as soon as possible. This implementation required the dispatch of professional teams to the positive sites within 24 hours to conduct a field survey and implement specific control measures. Required protection measures (e.g., extended chemotherapy) were applied in a timely manner to high-risk populations (e.g., humans and cattle). Finally, the efficacies of the response measures were evaluated.

Multi-distance spatial clustering analysis (Ripley's K function)

Ripley's K function is used to analyze whether spatial point data show statistically significant aggregation or dispersion within a certain scale. This analysis considers each case in the study area as a point on a plane, draws an epidemiological punctuation map based on its coordinates, and analyzes the spatial distribution pattern of cases in the study area based on the punctuation map. L(d) values are clustered outside the confidence interval and randomly distributed within the confidence interval. When the distribution is clustered, the deviation confidence interval value is used as the index of clustering intensity, where the maximum is the maximum clustering intensity and the clustering range is the circle whose distance is the radius. In this study, the Monte Carlo method was used to simulate 999 random simulations with a confidence interval of 95%. Ripley's L(d) index analysis was performed using ArcGIS software.

Kernel density estimation

Kernel density estimation is a non-parametric method used to estimate the probability density function. This method assumes that the disease can occur at any point in space, but the probability differs at different locations. The probability of disease occurrence is high in densely populated areas, and low in sparsely populated areas. Kernel density analysis and visualization was implemented using AcrGIS software.

Statistical analysis

The changes over time at the positive sites, rates and worm burdens were first explored through visual inspection including calculation of the mean values and dispersions, then compared using a χ^2 test. The analyses were performed using SPSS 22.0 (SPSS Inc. Chicago, USA). All spatially analyses were carried out using the spatial analyst module of ArcGIS 10.5 (ESRI; Redlands, USA), which has been widely applied in many fields of research.

Results

Distribution of sentinel mice surveillance sites

From 2010 to 2018, 190 sentinel mice surveillance sites were set up to detect areas of schistosomiasis infection (duplicate sites were removed) (Figure 1). The water regions included the Yangtze River, the Hanbei River, the Fu River and numerous other waterways. Most sites (n = 35) were set up in 2014 and the least number (n = 10) were set up in 2010 and 2012. The numbers of surveillance sites ranged from 12 to 33 in the other years. In 2011 and 2018, only one batch of sentinel mice was placed in June while two batches were placed in June and September in other years (Table 1).

Anatomical overview of the sentinel mice

From 2010 to 2018, a total of 4723 mice were gathered and dissected. The first and second batches included 3503 and 1220 dissected mice, respectively. The maximum number of sacrificed mice was 734 in 2014, and the minimum number was 360 in 2016. In other years, the numbers of sacrificed mice ranged from 397 to 663 (Table 1).

Detection and distribution of sites with positively infected sentinel mice

Details of the surveillance sites from which positively infected mice were identified are listed in Table 1. A total of 29 of the 190 sentinel mice sites yielded positive results, accounting for 15.26% (29/190). Of these, the highest occurrence rate was reported in 2010, at 90.00% (9/10), followed by83.33% (15/18) in 2011. No positively infected mice were detected in 2012, 2017 and 2018. The rates in other years ranged from 2.86% (1/35, 2014) to 12.50% (2/16, 2016) (Figure 2).

Regarding timed batches, 23 sites with positively infected mice were detected among the 167 sentinel mice sites from the first batch, yielding an occurrence rate of 13.17% (23/167). Of these, the highest occurrence rate was reported in 2011, at 83.30% (15/18), followed by 40.00% (4/10) in 2010. No positively infected mice were detected in the first batches of 2012, 2014, 2017 and 2018, whereas the rates ranged from 4.34% (1/23, 2015) to 20.00% (2/10, 2016) in other years. For the second batch, 8 sites with positively infected mice were detected among 61 sentinel mice sites, yielding an occurrence rate of 13.11% (8/61). Occurrence rates of 70.00% (7/10) and 12.50% (1/8) were reported in 2010 and 2014, respectively, whereas no sites with positively infected mice were identified in other years (the second batch was not obtained in 2011 and 2018). The differences in occurrence rates between the first batch and second batch in sites with positively infected mice were not statistically significant (x^2=0.02, P>0.05) (Table 1).

The infection rate and intensity among the sentinel mice

Among dissected 4723 mice, 112 positively infected mice and 256 adult worms were detected, yielding an infection rate of 2.37% and an average intensity of 2.28 worms/infected mice. The highest infection rate among the sentinel mice was 13.89% in 2011 (Figure 2). In 2015, the intensity among the sentinel mice was 4.2 (21/5), which was the highest during the 9-year period.

In the first batch, 99 positively infected mice and 229 adult worms were detected among a total of 3503 dissected mice, yielding an infection rate of 2.83% and an average intensity of 2.37 worms/infected mice. In the second batch, 13 positively infected mice and 27 adult worms were detected among 1220 dissected mice, yielding an infection rate of 1.07% and an average of 2.08 worms/infected mice. The differences in the positively infected mice rates between the first batch and second batch were statistically significant (x^2=12.11, P<0.01). The rates and intensity data are shown in Table 1.

Multi-distance spatial clustering analysis

When the distance was ≤34.52km, the observed Ripley's L(d) was outside the 95% confidence interval, indicating that the spatial distribution of the sentinel mice infection presented an aggregated pattern. When the distance was equal to 7.86km, the maximum aggregation was 13626.22. However, when the distance was >34.52km, the spatial pattern of sentinel mice infection presented a random distribution (Figure 3).

Kernel density estimation

Three aggregation areas were detected using kernel density estimation, namely: at the junction of Jingzhou District, Gongan County and Shashi District in Jingzhou City and; in Wuhan city at the border of the Huangpi and Dongxihu Districts and in Hanan and Caidian Districts (Figure 4).

Discussion

Implementing sentinel mice surveillance in key water regions within schistosomiasis-endemic areas facilitates determining the risk of schistosomiasis transmission and initiating an immediate response to protect local residents from infection [17, 18]. The nine years of surveillance involved 190 monitoring sites covering areas in the middle and lower reaches of the Yangtze River in its Hubei section, the Hanbei River, the Fu River and other waterways. The study results confirmed a significant reduction in schistosomiasis transmission in Hubei province, mainly due to the long-term schistosomiasis control plan implemented by the provincial government. This plan included measures such as an increased enforcement of effective snail monitoring and control at surveillance sites, which entailed environmental modification together with the use of molluscicidal agents to control potential *O. hupensis* habitats. Efforts to replace bovines with machinery have also increased the effectiveness of schistosomiasis control[24, 25].

Analyses of different batches demonstrated a significantly higher infection rate among the first batch relative to the second batch, indicating a higher level of water infectivity during the June–July period, compared to the September–October period. This result was in accordance with findings of previous reports, and suggests that the risk of schistosomiasis infection in key high-risk water regions is highest in June and July, which can be considered the critical period for acute schistosomiasis prevention and control[26, 27]. A comparison with previous studies revealed that infected mice were identified at rates ranging from 12.12–41.67% in areas where no infectious snails had been detected during the same year. In particular, an infection rate of 12% was detected among sentinel mice in areas where no infected snails had been detected for more than 3 years [28], suggesting that the use of the sentinel mouse method to monitor high-risk water regions during the flood season might dramatically improve the sensitivity of the schistosomiasis surveillance and forecast system [29, 30]. Moreover, the different infection rates shown in the batch results may also be related to the placement of the sentinel mice. For example, the first batch was set up once the river waters had just submerged the habitats of the *O. hupensis* snails, whereas the second batch was set up once the waters had receded, thus placing the mice far from the snail habitats. This suggests that the sentinel mice should not be placed at too great a distance from *O. hupensis* snail habitats [30, 31]. Studies of schistosomiasis water infectivity in the Dongting Lake region during both flooding and receding water stages have shown that cercaria shedding peaked in the Yangtze River once the floodwaters had just covered land containing *O. hupensis* snails, potentially leading to a high infectivity rate of the water region. This type of area and at that particular time would, therefore, provide the optimal setting for the sentinel mice[32, 33].

In this study, spatial aggregation data in relation to monitoring possible infection sites using sentinel mice in Hubei province from 2010 to 2018 were analyzed, combining Ripley's L(d) index analysis with kernel density estimation using GIS software. The Ripley's L(d) index analysis results showed that when the distance was ≤ 34.52 km, sentinel mice infection presented with aggregated pattern, with the strongest aggregation at 7.86 km. Kernel density estimation detected three hotspots of sentinel mice infection, all located along the Yangtze River. Two hotspots were located in Wuhan City where the Yangtze River meets the Han River. The city has many marshlands along rivers and lakes, which are suitable for *O.hupensis* breeding. One hot spot was located in the Fu-Lun River system in Huangpi and Dongxihu Districts, and another hotspot was located in the Dongjing-Tongshun River system in the Hanan and Caidian Districts. The high infection rate of sentinel mice may be closely related to the serious schistosomiasis endemicity of these two water systems.

The third hotspot was located at the junction of Jingzhou District, Gong'an County and Shashi District in Jingzhou City. In particular, the Juzhang River in Libu town within Jingzhou District is known as a high-risk area for schistosomiasis infection, and infected sentinel mice were detected there several times. Libu town is located at the initial section of the WDWYH project. It is widely acknowledged that the epidemiology of *S. japonicum* infections has a particular spatial characteristic in China because its epidemiology depends on the presence of *O.hupensis*, whose specific climatic and environmental conditions for reproduction govern the pattern of schistosomiasis distribution [34]. Because of the WDWYH, a large volume of water has been drained from the mainstream of the Yangtze River, leading to a rapid decrease in the Juzhang River water level, alongside numerous ecological environmental changes in relation to bottomland soil moisture, vegetation distribution, and microenvironment temperatures that perhaps have facilitated *O. hupensis* diffusion more quickly across the marshland [9].As indicated in other studies, the emergence or re-emergence of schistosomiasis might often be caused by newly-built hydro-electric projects in endemic areas, such as the Aswan Dam in Egypt, the Manantali Dam in Mali, the Tigay Dam in Ethiopia, the Gezira-Managil Dam in Sudan, and the Danling Dam in China [35–37]. The sentinel mice surveillance method can be employed to evaluate the effect of snail eradication measures, particularly in the spring. Our study results showed that the sentinel mice method was possibly more sensitive than conventional snail surveys, as the latter method failed to detect any infected *O. hupensis* in Libu town across the same years as this study.

This sentinel mouse-based surveillance and forecast method clarified the characteristics of schistosomiasis infection in the monitored waters and provided effective early warnings to help prevent the occurrence and transmission of acute schistosomiasis. Furthermore, this method has fostered a better understanding of the quality limitations of the snail survey method through providing an indirect check and evaluation of previous snail and cercaria control methods [38, 39]. The snail survey is a huge undertaking in the large snail habitats of schistosomiasis endemic areas of the Yangtze, Hanbei, and Fu Rivers. In systematic random sampling-based snail surveys, factors critical to detecting infected snails have tended to be missed at a distance exceeding 10 meters between two adjacent *O.hupensis* survey frames [40]. On the other hand, sentinel mouse surveillance can detect environments infected with schistosomes with greater sensitivity. This method should be implemented vigorously in key water regions and environments to improve the sensitivity of surveillance and forecasting in schistosomiasis-endemic areas and to further improve the quality of snail control, along with more human resources and material and financial support [41, 42].

Despite the benefits of the sentinel mice surveillance method, there is a limitation: acquiring relevant information quickly is challenging. Early warnings are difficult to provide as the maturation of schistosomes from schistosomula to adult worms takes > 28 days. Molecular assays may serve as potential alternatives to conventional sentinel mice dissection methods in situations where highly sensitive tests capable of gauging transmission risk in low-prevalence areas are needed [43]. Wang et al. showed that the specific antibodies IgM and IgG against Sj23HD in sentinel mice could be found at day 7 to 10 post-infection[44]. Nevertheless, the unknown extent of cross-reactivity with other helminths makes laboratory or field use impractical. Furthermore, circulating antigen-based methods have shown inconsistent sensitivity for low-intensity schistosomiasis infection in different studies; therefore, their utility for early detection of schistosomiasis, especially in cases of low-infection intensity, requires further assessment [45]. PCR-based methods show promise and may provide the sensitivity needed to detect very low intensity *S.japonicum* infections in regions approaching schistosomiasis elimination. A recent study showed that a nested-PCR assay was able to detect the specific 303-bp sequence at 3 days post-infection, without the limitations previously noted [5].Therefore, PCR-based methods to identify the presence of cercariae in water may aid in the identification of environments where the parasite remains endemic.

Conclusion

The example of successful schistosomiasis prevention and control measures in Hubei province is likely to help with reducing infection levels in other schistosomiasis-endemic areas and lead to an increased demand for surveillance and forecasting. Our results revealed that the sentinel mice surveillance method was useful in precisely determining high-risk environments and in providing early warning information to local residents. Specifically, the use of the sentinel mouse method to monitor schistosomiasis-risk environments during flood seasons and evaluate surveillance and forecasting methods in key water regions has led to the accumulation of relevant local data from 2010 to 2018 in Hubei province that more precisely reflects the variations in schistosomiasis endemicity within the province. The areas along the Yangtze River, especially the Fu-Lun River, the Dongjing-Tongshun River and the Juzhang River basin are key regions in which efforts for the prevention and control of schistosomiasis need to be directed in future. Furthermore, more sensitive surveillance measures, such as PCR-based methods, should also be used to detect schistosomiasis-endemic risk in regions approaching schistosomiasis elimination.

Table

Table 1.Positive infection rates and intensity in sentinel mice in Hubei provincial schistosomiasis surveillance sites (2010-2018)

Year	First batch(June)					Second batch (September)					Total*				
	No. Sites detected	Occurrence rate of positive sites(%)	No. mice dissected	Positive rate of mice(%)	Mean Worm burden of positive mice	No. Sites detected	Occurrence rate of positive sites(%)	No. mice dissected	Positive rate of mice(%)	Mean Worm burden of positive mice	No. Sites detected	Occurrence rate of positive sites(%)	No. mice dissected	Positive rate of mice(%)	Mean Worm burden of positive mice
2010	10	40	198	5.56	2.18	10	70	200	5.5	1.91	10	90	398	5.53	2.05
2011	18	83.3	540	13.89	2.29	0	0	0	0	0	18	83.3	540	13.89	2.29
2012	10	0	200	0	0	10	0	197	0	0	10	0	397	0	0
2013	12	8.3	229	1.31	2.33	12	0	240	0	0	12	8.3	469	0.64	2.33
2014	29	0	574	0	0	8	12.5	160	1.25	3	35	2.86	734	0.27	3
2015	23	4.34	450	1.11	4.2	5	0	103	0	0	26	3.85	553	0.9	4.2
2016	10	20	200	2.5	1	8	0	160	0	0	16	12.5	360	1.39	1
2017	25	0	503	0	0	8	0	160	0	0	33	0	663	0	0
2018	30	0	609	0	0	0	0	0	0	0	30	0	609	0	0
Total	167	13.77	3503	2.83	2.37	61	13.11	1220	1.07	2.08	190	15.26	4723	2.37	2.28

* Duplicate sites were removed

Declarations

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Authors' contributions

Y-YC, SL, J-BL, and GL conceived the paper. Y-YC, X-WS, HW, BL, and GL performed the literature search, prepared the figures, and interpreted the data. Y-YC and GL wrote the manuscript. X-WS, BL, J-JY, L-FD and J-BL assisted in the restructuring and revision of the manuscript. All authors read, contributed to, and approved the final version.

Ethical Approval and Consent to participate

This study were designed by National Institute of parasitic diseases, Chinese Center for Disease Control and Prevention, and approved by the Committee on the

Consent for publication

Not applicable

Availability of supporting data

The dataset used in the study is available from the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Figures

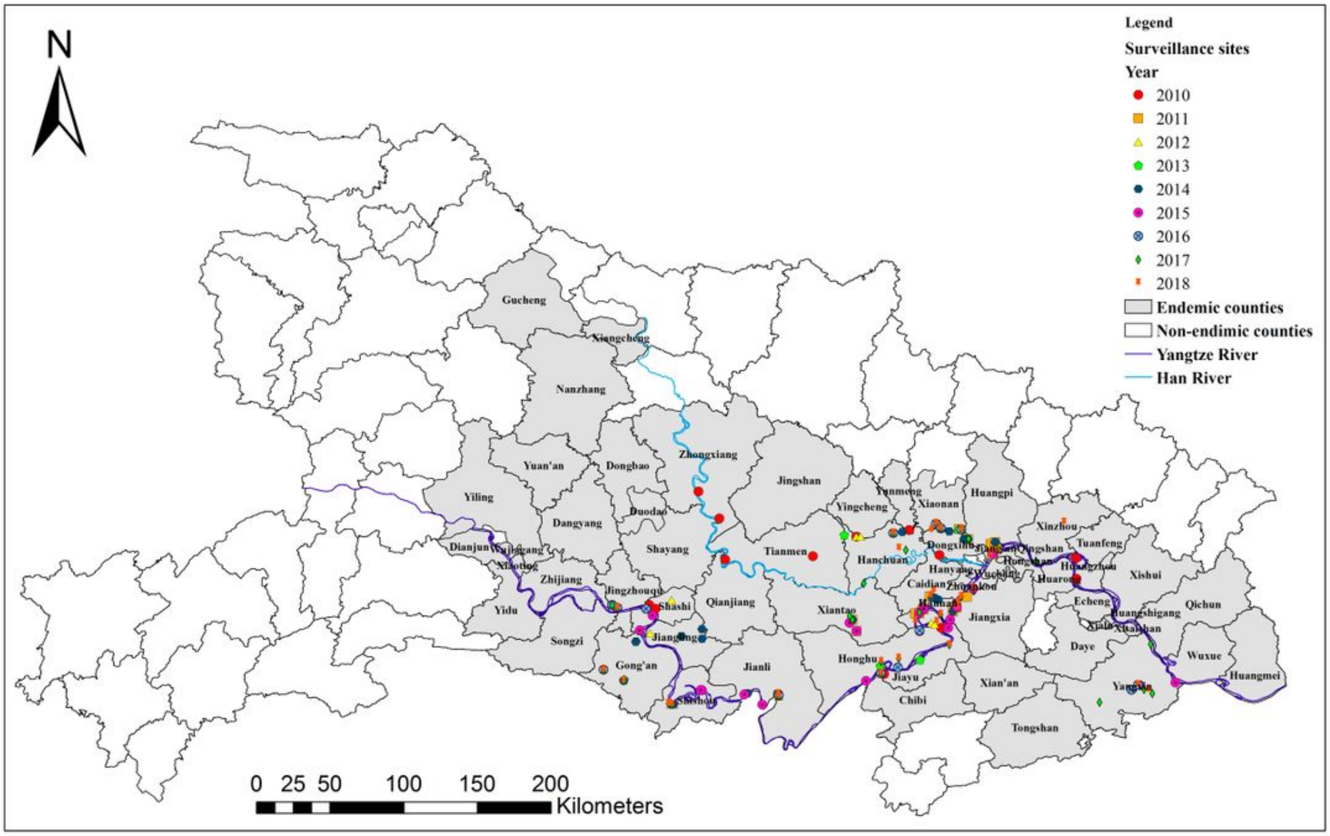

Figure 1

Distribution maps of sentinel mice surveillance sites in Hubei province (2010-2018). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

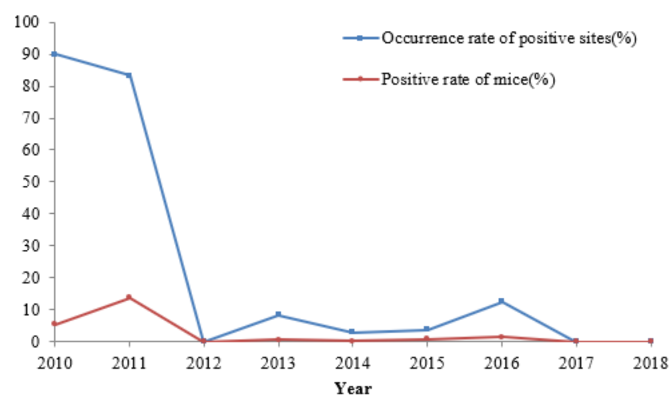

Figure 2

A diagram showing variations in sentinel mice surveillance result in Hubei province (2010-2018)

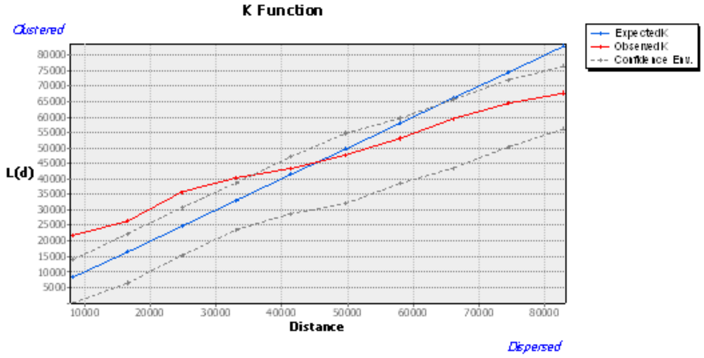

Figure 3

Ripley's L(d) index analysis of sentinel mice infection rates in Hubei province (2010-2018)

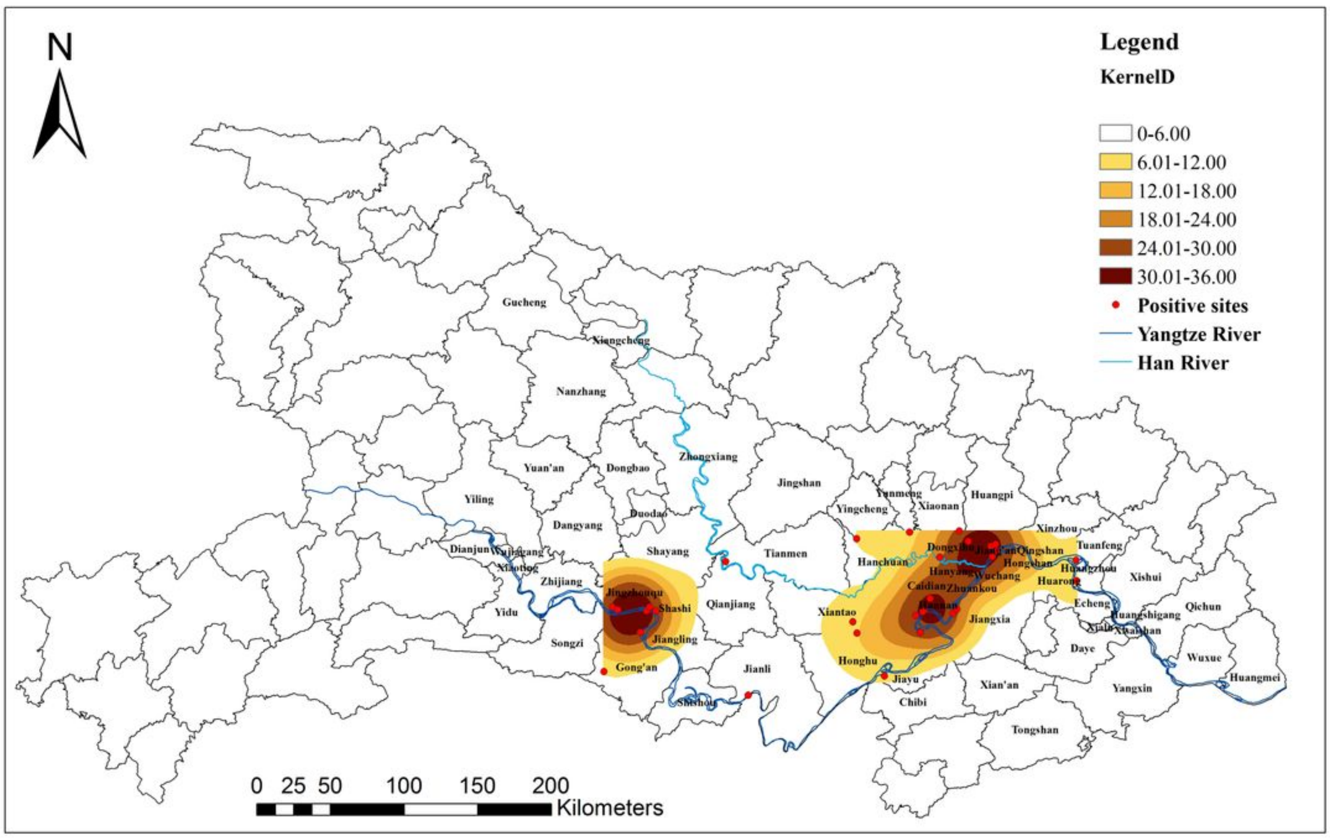

Figure 4

Kernel density estimation of positive sentinel mice sites in Hubei. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.