Three Gorges Dam: the changing trend of snail density in the Yangtze River basin between 1990 and 2019

Yanfeng Gong[1,2,3], Yixin Tong[1,2,3], Honglin Jiang[1,2,3], Ning Xu[1,2,3], Jiangfan Yin[1,2,3], Jiamin Wang[1,2,3], Junhui Huang[1,2,3], Yue Chen[4], Qingwu Jiang[1,2,3], Shizhu Li[5,6*] and Yibiao Zhou[1,2,3*]

Abstract

Background The area of *Oncomelania hupensis* snail remains around 3.6 billion m^2, with newly emerging and reemergent habitats continuing to appear in recent years. This study aimed to explore the long-term dynamics of snail density before and after the operation of Three Gorges Dam (TGD).

Methods Data of snail survey between 1990 and 2019 were collected from electronic databases and national schistosomiasis surveillance. Meta-analysis was conducted to estimate the snail density. Joinpoint model was used to identify the changing trend and inflection point. Inverse distance weighted interpolation (IDW) was used to determine the spatial distribution of recent snail density.

Results A total of 3777 snail survey sites with a precise location of village or beach were identified. For the downstream area, snail density peaked in 1998 (1.635/0.11 m^2, 95% *CI:* 1.220, 2.189) and fluctuated at a relatively high level before 2003, then declined steadily from 2003 to 2012. Snail density maintained lower than 0.150/0.11 m^2 between 2012 and 2019. Joinpoint model identified the inflection of 2003, and a significant decreasing trend from 2003 to 2012 with an annual percentage change (APC) being − 20.56% (95% *CI:* − 24.15, − 16.80). For the upstream area, snail density peaked in 2005 (0.760/0.11 m^2, 95% *CI:* 0.479, 1.207) and was generally greater than 0.300/0.11 m^2 before 2005. Snail density was generally lower than 0.150/0.11 m^2 after 2011. Snail density showed a significant decreasing trend from 1990 to 2019 with an APC being − 6.05% (95% *CI:* − 7.97, − 7.09), and no inflection was identified. IDW showed the areas with a high snail density existed in Poyang Lake, Dongting Lake, Jianghan Plain, and the Anhui branch of the Yangtze River between 2015 and 2019.

Conclusions Snail density exhibited a fluctuating downward trend in the Yangtze River basin. In the downstream area, the operation of TGD accelerated the decline of snail density during the first decade period, then snail density fluctuated at a relatively low level. There still exists local areas with a high snail density. Long-term control and monitoring of snails need to be insisted on and strengthened.

Keywords *Oncomelania hupensis*, Snail, Three Gorges Dam, Environmental change, Long-term trend, Schistosomiasis japonica

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*Correspondence:
Shizhu Li
lisz@chinacdc.cn
Yibiao Zhou
ybzhou@fudan.edu.cn
Full list of author information is available at the end of the article

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Background

Schistosomiasis is water-borne helminthiasis that affects more than 250 million people with approximately 800 million at risk worldwide [1–3]. In China, schistosomiasis caused by *Schistosoma japonicum* is a zoonotic parasitic disease transmitted by water contact [4]. *Oncomelania hupensis* snail is responsible for the transmission of schistosomiasis japonica [5]. Over the past 70 years, China has implemented comprehensive schistosomiasis control measures focusing on snail control (1950–1985), large-scale chemotherapy (1985–2004) and infectious source control (2005–), and made remarkable achievements [6, 7]. Currently, the major endemic areas concentrate on the seven provinces of the Yangtze River basin, which can be divided into the hilly epidemic area at the upstream of The Three Gorges Dam (TGD) and epidemic area dominated lake and marshland at the downstream of TGD [8].

TGD began filling with water in 2003, and the water level subsequently rose to the heights of 135 m (2003–2005), 156 m (2006–2007), and 175 m (2008–2012) [9]. The impoundment of the TGD has a long-term influence on the water level and the ecological environment in the middle and lower reaches of the Yangtze River [10], which make up approximately 96.8% of the *O. hupensis* habitats in China [11]. The increase of extreme weather events over the past decades such as floods in 1991, 1998 and 2016, droughts in 2006 and 2010, snow storm in 2008, undoubtedly affected the distribution of snail population. The impact of environmental change on snail distribution has invoked heated attention. Numerous studies have been conducted to explore the impact of environmental changes on the snail distribution and the spread of schistosomiasis [12–20]. However, little is known about their impact on the dynamics of snail density [12–20].

The abundance of snails can promote schistosomiasis transmission, so understanding the dynamics and spatial distribution of snail density is critical for schistosomiasis risk assessment and snail control [21–23]. However, most previous studies on the distribution of snail focused on the suitability probability, and rarely quantified the snail density [25–29]. In this study, we conducted a meta-analysis to study the long-term dynamics of snail density from 1990 to 2019 by collecting snail survey data with precise location of the village or beach from multiple data sources, and spatial interpolation to analyze the spatial characteristics of recent snail density.

Methods

Literature review

The articles associated with snail density from January 1, 1990 to November 21, 2022 were retrieved from four electronic bibliographic databases, i.e., China National Knowledge Infrastructure (CNKI, https://www.cnki.net/), Wanfang Database (https://www.wanfangdata.com.cn/), PubMed/MEDLINE, and Science Citation Indexed Expanded (SCIE). The search terms were: "schistosomiasis or snail or *Oncomlania hupensis*" and "survey or surveillance or monitor or density". Relevant literature was also checked manually by searching the reference lists. The criteria of articles included in our study were: (1) a study was conducted in the seven provinces (downstream of the TGD: Hunan, Hubei, Jiangxi, Anhui and Jiangsu; upstream of the TGD: Sichuan and Yunnan); (2) the survey time was clearly reported, at least to a specific year; (3) specific survey location was provided, specifically to village or beach; (4) the number of survey frames and the number of living snails were included, or it can be calculated by the formula (living snail density = the number of living snail/the number of surveyed frames); (5) non-review articles; (6) Full text is available. If any one of the above standards is not met, it shall be excluded. If two articles published the same research data, the article with less information was excluded. There are few articles reporting the snail survey after 2019 to date; therefore, our research focused on the period from 1990 to 2019.

Data extraction

All research documents were imported into the document management software NoteExpress3.7 (Beijing Aegean Hailezhi Technology Co., Beijing, China) and duplicate records were eliminated. Two researchers independently conducted a preliminary screening of each identified title and abstract, and then read the full text for a second screening. Relevant information for each study was extracted using pre-designed Microsoft Excel tables, including references, survey time (year), study location (province, village or beach), the number of surveyed frames, the number of living snails, and density of living snails. Similar information was also collected from the national schistosomiasis surveillance for the period from 1990 to 2019.

Data analysis

Meta-analysis

Snail density and its 95% confidence interval (*CI*) were integrated for the upstream and downstream of the TGD, respectively, for the whole study period (1990–2019), and subgroup analysis was conducted according to the survey year to obtain the annual density of snails. The heterogeneity between studies was assessed using Cochran's Q (chi-square) test and quantified by Higgins inconsistency statistic (I^2) [30]. I^2 indicates whether a difference between studies is caused by heterogeneity rather than chance, and the values of 25%, 50% and 75% correspond to low, medium, and substantial

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heterogeneity [31]. When there was substantial heterogeneity ($I^2 > 50\%$), a random effect model was used to combine snail density estimates; otherwise, a fixed effect model was used [32]. All the meta-analyses were performed with Stata17.0 (Stata Corp., College Station, Texas, USA).

Changing trend of snail density

Joinpoint model was used to explore the changing trend of snail density for the period between 1990 and 2019 (Joinpoint Regression Program 4.8.0.1, National Cancer Institute, Rockville, MD, USA). Logarithmic linear model for trend was selected to calculate the annual percentage change (APC) and its 95% *CI* [33]. APC is a dimensionless relative number, which only reflects the direction and speed of the trend change. APC < 0 indicates that the snail density decreases with time, APC > 0 indicates that the snail density increases with time [34]. A replacement test was used to determine the number of connection points and the position of each connection point, and to test whether the trend of snail density for each time segment was statistically significant.

Surface interpolation to estimate mean snail density

In order to explore the spatial characteristics of recent snail density, the survey data between 2015 and 2019 were used. Snail density at the same point was averaged for the period between 2015 and 2019, and then inverse distance weighted (IDW) interpolation was used to estimate the mean density of snails. IDW is a deterministic spatial interpolation method, which takes the spatial distance between object points as a weight [35]. The closer the distance is, the greater the weight is [35]. The formula for calculating the estimated average snail density D at the interpolation point is as follows [36]:

$$D = \sum_{i=1}^{n} \omega_i D(s_i)$$

n represents the number of known snail points; $D(s_i)$ is mean snail density at the snail point s_i; ω_i is Weight of sample point s_i. Weight ω_i is calculated as follows [36]:

$$\omega_i = \frac{d_i^{-P}}{\sum_{i=1}^{n} d_i^{-P}}$$

d_i is the distance between the prediction snail point *s* and the known snail point s_i. *P* is the power of the distance. The larger the exponent value, the greater the influence of the closer snail sample points on the result. The interpolation analysis was performed with ArcGIS 10.2 software (Esri, Redlands, CA, USA).

Results

Sites of snail surveys included in the current analysis

A total of 5628 articles were identified from the 4 electronic databases. Of them, 2836 articles were removed due to duplication, 1754 were irrelevant by screening the title or abstract, and 694 were excluded after screening 1038 full-text articles (Fig. 1). In addition, 2271 survey sites in the 7 provinces were identified from the national surveillance data, and 328 of them were excluded due to the same data sites identified from the research articles (Fig. 1). Finally, the analysis included 1834 independent survey sites from research articles and 1943 independent survey sites from the surveillance for the period between 1990 and 2019, and 872 were located at the upstream area of TGD and 2905 at the downstream of the TGD. The location of these independent survey sites is presented in Additional file 1: Fig. S1.

Changing trend of snail density

There was heterogeneity between studies (upstream area: $Q = 3.4\text{e} + 06$, $P < 0.001$, $I^2 = 99.99\%$; downstream area: $Q = 1.2\text{e} + 07$, $P < 0.001$, $I^2 = 99.99\%$), a random effect model was used to estimate the density of snails. The overall density in the downstream area was 0.353/0.11 m^2 (95% *CI*: 0.329, 0.378) compared with 0.180/0.11 m^2 (95% *CI*: 0.159, 0.203) in the downstream area. The annual snail density showed a decreasing trend for both areas (Fig. 2).

For the downstream area of the TGD (i.e., the lake and marshland regions) (Fig. 2A), the snail density declined significantly from 1.430/0.11 m^2 (95% *CI*: 0.943, 2.169) in 1990 to 0.106/0.11 m^2 (95% *CI*: 0.082, 0.136) in 2019. There were notable fluctuations for the period between 1990 and 2003. The snail density declined steadily from 2003 (1.142/0.11 m^2, 95% *CI*: 0.765, 1.707) to 2012 (0.127/0.11 m^2, 95% *CI*: 0.081, 0.199). Between 2012 and 2019, the density fluctuated slightly and maintained lower than 0.150/0.11 m^2. Three inflection points were identified by Joinpoint model in the downstream area: 1998, 2003, and 2012. However, only the inflection of 2003 was statistically significant, and the snail density showed a significant downward trend from 2003 to 2012 with an APC being − 20.56% (95% *CI*: − 24.15, − 16.80) (Fig. 3A).

For the upstream area of the TGD (hilly region) (Fig. 2B), the snail density decreased from 0.451/0.11 m^2 (95% *CI*: 0.241, 0.844) in 1990 to 0.115/0.11 m^2 (95% *CI*: 0.079, 0.167) in 2019. Before 2005, the snail density fluctuated but was generally greater than 0.300/0.11 m^2, and peaked in 2005 (0.760/0.11 m^2, 95% *CI*: 0.479, 1.207). The snail density declined since 2006, and was generally lower than 0.150/0.11 m^2 between 2011 and 2019. No inflection

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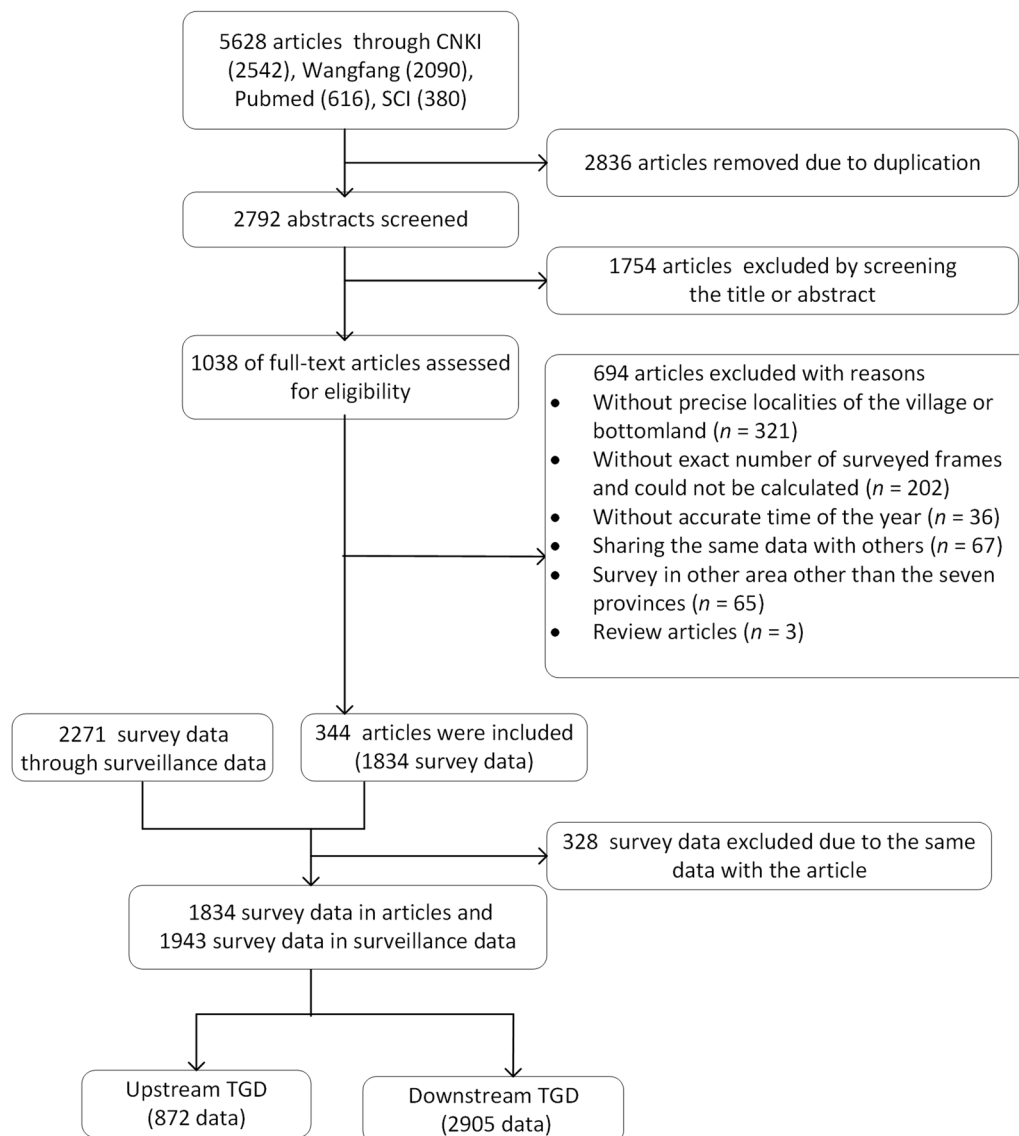
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Fig.1 Flow chart of search and selection of articles

point was identified based on the Joinpoint model, and the snail density showed a significant downward trend from 1990 to 2019 with an APC being -6.05% (95% *CI:* $-7.97, -7.09$) (Fig. 3B).

Spatial distribution of snail density

Between 2015 and 2019, a total of 349 independent survey locations (villages or beaches) were identified, and 125 of them had the snail density of zero at some of the sampling times. There were 21 localities where snail density was from $0.001/0.11$ m^2 to $0.020/0.11$ m^2, 55 localities with snail density ranged from $0.021/0.11$ m^2 to $0.100/0.11$ m^2, 76 localities with snail density ranged from $0.101/0.11$ m^2 to $0.300/0.11$ m^2, 40

localities with snail density ranged from $0.301/0.11$ m^2 to $0.500/0.11$ m^2) and 31 localities with snail density more than $0.500/0.11$ m^2, respectively (Additional file 1: Fig. S2).

IDW showed that snails were concentrated along the Yangtze River in the lake and marshland regions and dispersed in the mountain region, with a higher snail density in the downstream area of the TGD than the upstream area between 2015 and 2019. The downstream area with a higher snail density ($>0.101/0.11$ m^2) existed in Poyang Lake, Dongting Lake, Jianghan Plain, and the Anhui branch of the Yangtze River, and the upstream area with a higher snail density ($>0.021/0.11$ m^2) existed in the

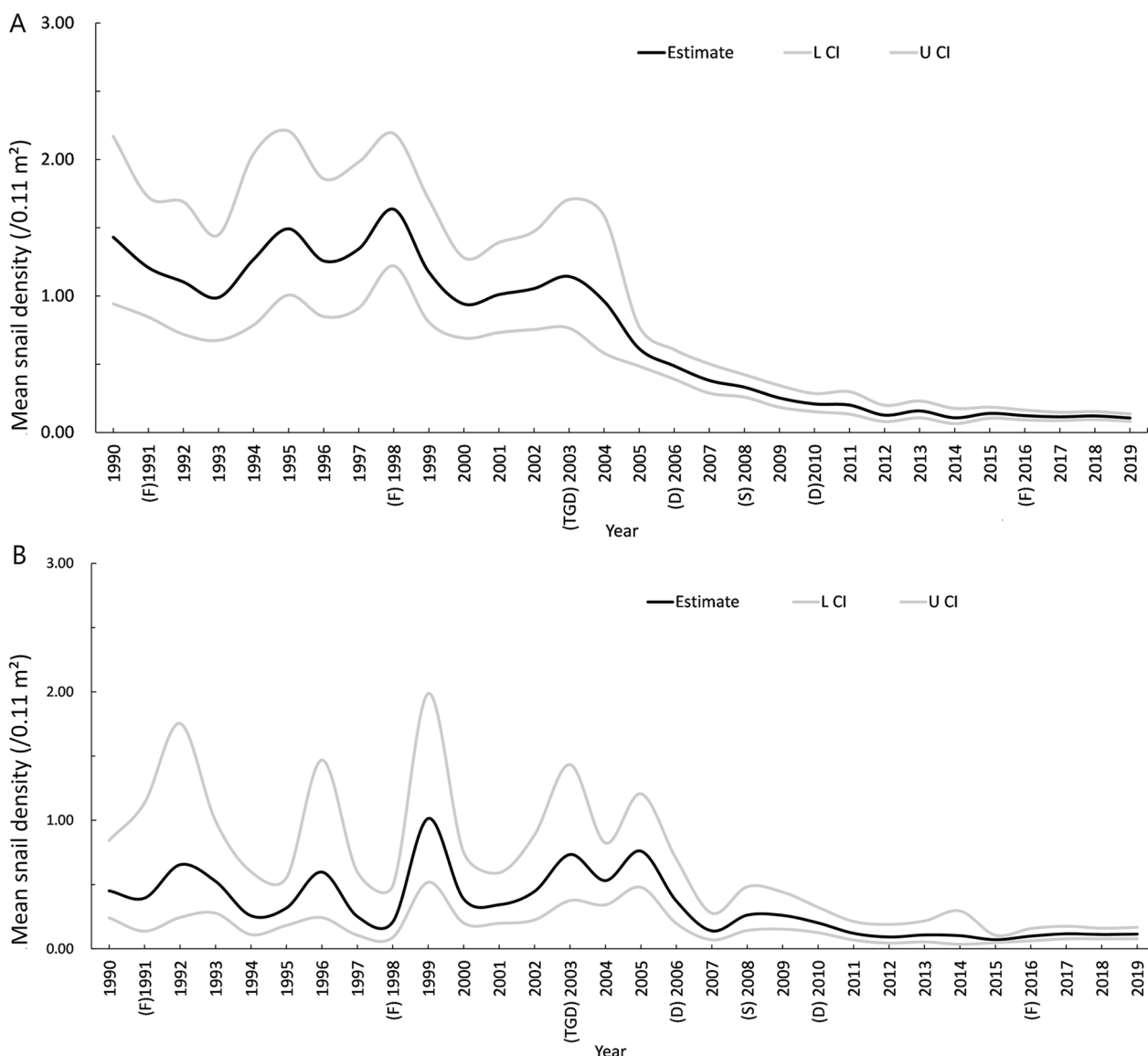Gong *et al. Infectious Diseases of Poverty*   (2023) 12:45

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Fig.2 Estimation of the mean density of *O. hupensis* snails between 1990 and 2019. **A** The downstream area of TGD; **B** the upstream area of TGD). *F* Flood; *TGD* Three Gorges Dam; *D* Drought; *S* Snow; *L CI* Lower limit of the 95% confidence interval; *U CI* Upper limit of the 95% confidence interval

Chengdu plain, Daliang Mountain area of Sichuan, and the north-west area of Yunnan (Additional file 1: Fig. S2).

Discussion

This study used meta-analysis to explore the dynamics of snail density over a 30-year period as well as the changing trend. The snail density demonstrated a fluctuating downward trend between 1990 and 2019, which is mainly due to the continuous promotion of snail control. The considerable changes in snail density were in line with major environmental changes such as TGD operation in 2003, devastating floods in 1991 and 1998.

Our study demonstrated that the year 2003 was a significant turning point for the snail density change in the downstream area of TGD. The APC of snail density in the downstream area was − 20.56% (95% *CI:* − 24.15, − 16.80) between 2003 and 2012, significantly higher than that in other time periods, while the snail density showed an upward trend in the upstream area between 2003 and 2005. Similar results were found that the snail density was decreasing after the TGD operation [37–39]. Considerable changes have been observed in water level, weed, and silt sediment after the TGD operation [40–42], which further impacted the ecological environment of
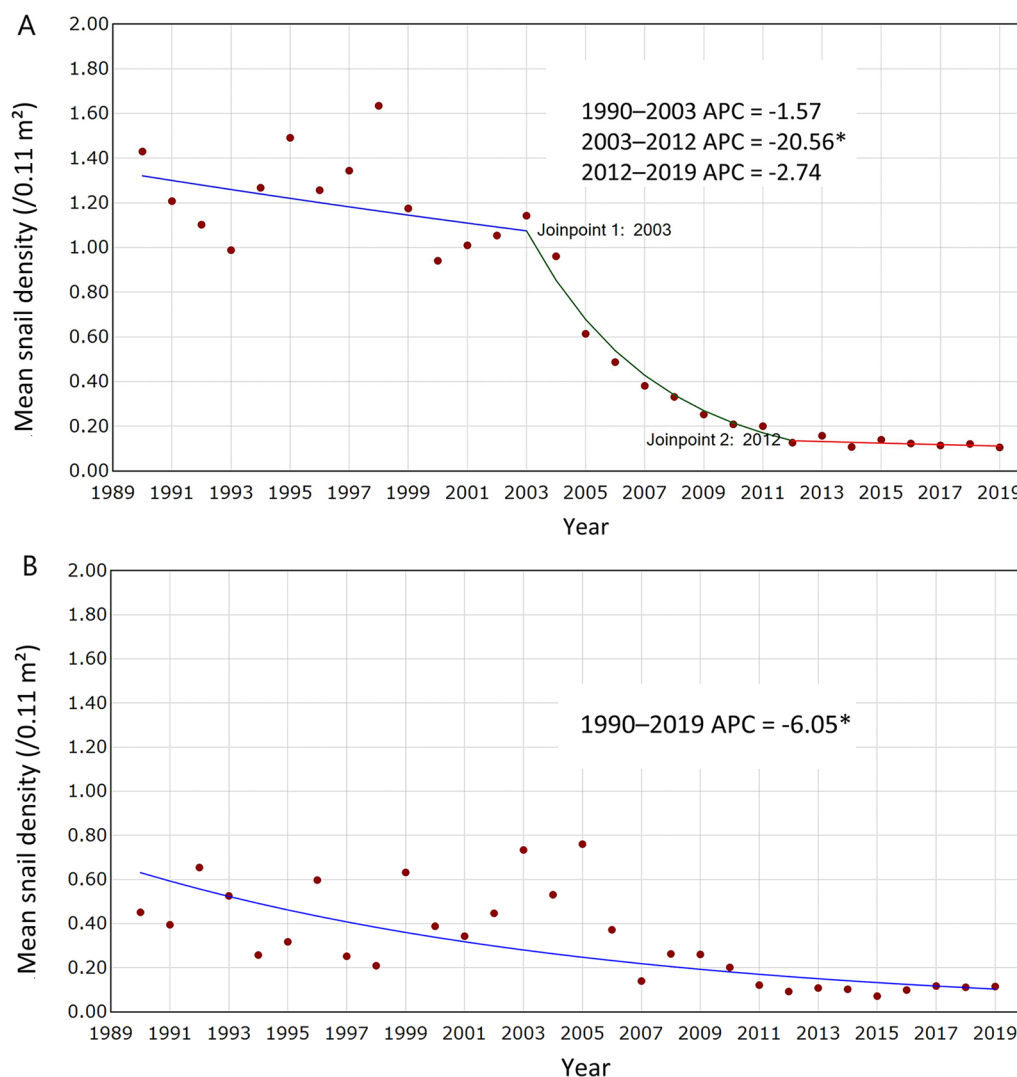
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Fig. 3 Changing trend of *O. hupensis* snail density between 1990 and 2019. **A** The downstream area of TGD; **B** the upstream area of TGD). * denotes *P* < 0.05; *APC* Annual percentage change

snail survival [43]. After TGD was put into operation, the lowering of water levels during flood seasons and the early water recession in autumn would lead to a change of the microenvironment of most bottomlands [44, 45]. As a result, the bottomland, especially in the middle and high elevation, was no longer conducive to the growth of reeds, which reduced the snail survival rate [46]. In addition, low water levels destroyed "winter-land and summer-water" characteristics that were suitable for snail breeding [47, 48]. The TGD has deteriorated the ecological conditions for snail survival and reproduction and compressed their living space, resulting in a fast decrease in snail density.

This study demonstrated that the snail density in the downstream area of TGD decreased for the first two

years after a flood (i.e., floods in 1991 or 1998), then increased. These results were in accordance with the longitudinal observation of snail density after the flood in the middle and lower reaches of the Yangtze River [50, 51]. The survival and breeding of snails in the marshland not only depend on suitable climate and abundant food [52] but are also closely associated with the flooding [53, 54]. Submergence during summer is essential for the growth of newly hatched snails but has detrimental effects on the ability of adult snails to survival [55, 56]. The continuous high-level water, as well as the relatively long flooding duration, was not conducive to the survival of adult snails [57]. Most snails cannot survive in fast-flow water, and sediment deposition may result in the death of snails [50]. Despite having a limited ability

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of mobility, snails can spread over a great distance along with floating objects during a flood. Snail can spread to snail-free or snail-eliminated environments, which may result in the appearance of newly breeding habitats [27, 58]. Therefore, the decline in the first two years after a flood can be attributed to the high mortality of adult snails and the spread of snails to newly emerging and re-emergent habitats [58]. The subsequent recovery in the third year may be due to the growth and development of new young snails.

This study also observed that the snail density decreased after a drought year in the hilly region. Snails are likely to die when drought conditions are severe and frequent [14]. Severe drought caused many water sources to dry up and the soil to become dry, which was unfavorable for snail spawning and incubation [59–61]. This may explain the temporary decline of the snail density after the drought year of 2006 or 2010.

With respect to the snail density threshold (0.020/0.11 m^2) that blocks schistosomiasis transmission, a snail density greater than that is considered to be capable of transmitting schistosomiasis [62]. Our study found that the infested areas with a higher snail density mainly existed in Poyang Lake, Dongting Lake, Jianghan Plain, and the Anhui branch of the Yangtze River. The aforementioned areas in the middle and lower reaches of the Yangtze River form a healthy grassland wetland ecosystem for snail breeding due to the seasonal and cyclical changes in water levels [63–65]. Snail density in the mountainous region is generally lower than that in the marshland, but the snails are primarily found in ditches and rice fields in hilly regions [66]. Therefore, snail detection and molluscicide are relatively complicated due to the unique natural environment and the low economic status [67], making it easy for snail density to rebound. "Health China 2030" indicates the degree of vector control is a crucial sign of a healthy city or village [68, 69]. Due to the impact of extreme weather events and water conservancy, controlling the snail density below the threshold for spreading schistosomiasis remains a significant challenge, especially in local areas with a higher snail density [68, 69]. The findings imply the focus of snail control, and it is recommended to strengthen snail monitoring and control in the focus area.

This study has some limitations. First, this study did not include other influencing factors of snail density. Second, spatial interpolation can only indicate the key area of snail density on a large scale. Further study is needed to build correlation models that include meteorological, hydrological, vegetation, and other determinants to predict fine-scale snail density.

Conclusions

Our study provided strong evidence that the snail density exhibited a fluctuating downward trend in the Yangtze River Basin between 1990 and 2019. In the downstream area, the operation of TGD accelerated the decline of snail density during the first decade period, then snail density fluctuated at a relatively low level. The areas with a high snail density existed in Poyang Lake, Dongting Lake, Jianghan Plain, and the Anhui branch of the Yangtze River in recent years. Long-term control and monitoring of snails need to be insisted on and strengthened.

Abbreviations

TGD	Three Gorges Dam
APC	Annual percentage change
I^2	Higgins inconsistency statistic
IDW	Inverse distance weighted
DALY	Disability-adjusted life year

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40249-023-01095-y.

> Additional file 1: Figure S1. Spatial distribution of the sample points between 1990–2019. Figure S2. Mean snail density between 2015 and 2019.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical review and approval were not required for the study in accordance with the local legislation and institutional requirements.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Fudan University School of Public Health, Building 8, 130 Dong'an Road, Xuhui District, Shanghai 200032, China. [2]Key Laboratory of Public Health Safety, Fudan University, Ministry of Education, Building 8, 130 Dong'an Road, Xuhui District, Shanghai 200032, China. [3]Fudan University Center

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for Tropical Disease Research, Building 8, 130 Dong'an Road, Xuhui District, Shanghai 200032, China. ⁴School of Epidemiology and Public Health, University of Ottawa, 600 Peter Morand Crescent, Ottawa, ON K1G 5Z3, Canada. ⁵National Institute of Parasitic Diseases, Chinese Center for Disease Control and Prevention, Shanghai 200025, China. ⁶Chinese Center for Tropical Diseases Research, NHC Key Laboratory of Parasite and Vector Biology, Shanghai 200025, China.

References

1. Faust CL, Osakunor DNM, Downs JA, Kayuni S, Stothard JR, Lamberton PHL, et al. Schistosomiasis control: Leave no age group behind. Trends Parasitol. 2020;36(7):582–91.
2. WHO. Schistosomiasis and soil transmitted helminthiases progress report. Wkly Epidemiol Rec. 2001;48(96):585–95.
3. Lo NC, Bezerra FSM, Colley DG, Fleming FM, Homeida M, Kabatereine N, et al. Review of 2022 WHO guidelines on the control and elimination of schistosomiasis. Lancet Infect Dis. 2022;22(11):e327–35.
4. Li S, Shi Y, Deng W, Ren G, He H, Hu B, et al. Spatio-temporal variations of emerging sites infested with schistosome-transmitting *Oncomelania hupensis* in Hunan province, China, 1949–2016. Parasit Vectors. 2021;14(1):7.
5. Zhou YB, Liang S, Jiang QW. Factors impacting on progress towards elimination of transmission of schistosomiasis japonica in China. Parasit Vectors. 2012;5:275.
6. Li L, Zhou Y, Wang T, Zhang S, Chen G, Zhao G, et al. Elimination of *Schistosoma japonicum* transmission in China: a case of schistosomiasis control in the severe epidemic area of Anhui Province. Int J Environ Res Public Health. 2019;16(1):138.
7. Qian MB, Chen J, Bergquist R, Li ZJ, Li SZ, Xiao N, et al. Neglected tropical diseases in the People's Republic of China: progress towards elimination. Infect Dis Poverty. 2019;8(1):86.
8. Gong YF, Feng JX, Luo ZW, Xue JB, Guo ZY, Zhang LJ, et al. Spatiotemporal heterogeneity of schistosomiasis in mainland China: evidence from a multi-stage continuous downscaling sentinel monitoring. Asian Pac J Trop Med. 2022;15(1):26–34.
9. Chen YY, Cai SX, Xiao Y, Shan XW, Zhang J, Liu JB. Impact of implementation of Three Gorges project on schistosomiasis endemic situation in Hubei Province. Chin J Schisto Control. 2014;26(05):498–503 (In Chinese).
10. Dai SM, Edwards J, Guan Z, Lv S, Li SZ, Zhang LJ, et al. Change patterns of *Oncomelania* snail burden in areas within the Yangtze River drainage after the three gorges dam operated. Infect Dis Poverty. 2019;8(1):48.
11. Zheng JX, Xia S, Lv S, Zhang Y, Bergquist R, Zhou XN. Infestation risk of the intermediate snail host of *Schistosoma japonicum* in the Yangtze River Basin: improved results by spatial reassessment and a random forest approach. Infect Dis Poverty. 2021;10(1):74.
12. Li Z, Nie X, Zhang Y, Huang J, Huang B, Zeng G. Assessing the influence of water level on schistosomiasis in Dongting Lake region before and after the construction of Three Gorges Dam. Environ Monit Assess. 2016;188(1):28.
13. Gong YF, Zhu LQ, Li YL, Zhang LJ, Xue JB, Xia S, et al. Identification of the high-risk area for schistosomiasis transmission in China based on information value and machine learning: a newly data-driven modeling attempt. Infect Dis Poverty. 2021;10(1):88.
14. McCreesh N, Booth M. Challenges in predicting the effects of climate change on *Schistosoma mansoni* and *Schistosoma haematobium* transmission potential. Trends Parasitol. 2013;29(11):548–55.
15. Senghor B, Diaw OT, Doucoure S, Seye M, Talla I, Diallo A, et al. Study of the snail intermediate hosts of urogenital schistosomiasis in Niakhar, region of Fatick, West central Senegal. Parasit Vectors. 2015;8:410.
16. Xu XJ, Yang XX, Dai YH, Yu GY, Chen LY, Su ZM. Impact of environmental change and schistosomiasis transmission in the middle reaches of the Yangtze River following the Three Gorges construction project. Southeast Asian. J Trop Med Public Health. 1999;30(3):549–55.
17. Xue JB, Wang XY, Zhang LJ, Hao YW, Chen Z, Lin DD, et al. Potential impact of flooding on schistosomiasis in Poyang lake regions based on multi-source remote sensing images. Parasit Vectors. 2021;14(1):116.
18. Wang HY, Zhou YB, He Z, Li JX, Zhang ZJ, Peng WX, et al. Field observation on survival of *Oncomelania hupensis* in Dongting Lake area under a long period of snow weather. Chin J Schisto Control. 2008;20(5):339–41 (in Chinese).
19. Zhu R, Gray DJ, Thrift AP, Williams GM, Zhang Y, Qiu DC, et al. A 5-year longitudinal study of schistosomiasis transmission in Shian village, the Anning River Valley, Sichuan province, the Peoples' Republic of China. Parasit Vectors. 2011;4:43.
20. 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(2):199–205.
21. Perez-Saez J, Mande T, Ceperley N, Bertuzzo E, Mari L, Gatto M, et al. Hydrology and density feedbacks control the ecology of intermediate hosts of schistosomiasis across habitats in seasonal climates. Proc Natl Acad Sci USA. 2016;113(23):6427–32.
22. Feng Z, Li CC, Milner FA. Schistosomiasis models with density dependence and age of infection in snail dynamics. Math Biosci. 2002;177–178:271–86.
23. Li YL, Dang H, Guo SY, Zhang LJ, Feng Y, Ding SJ, et al. Molecular evidence on the presence of *Schistosoma japonicum* infection in snails along the Yangtze River, 2015–2019. Infect Dis Poverty. 2022;11(1):70.
24. Lu XT, Gu QY, Limpanont Y, Song LG, Wu ZD, Okanurak K, et al. Snail-borne parasitic diseases: an update on global epidemiological distribution, transmission interruption and control methods. Infect Dis Poverty. 2018;7(1):28.
25. Gong YF, Luo ZW, Feng JX, Xue JB, Guo ZY, Jin YJ, et al. Prediction of trends for fine-scale spread of *Oncomelania hupensis* in Shanghai Municipality based on supervised machine learning models. Chin J Schisto Control. 2022;34(3):241–51 (in Chinese).
26. Xue J, Hu X, Hao Y, Gong Y, Wang X, Huang L, et al. Transmission risk predicting for schistosomiasis in mainland China by exploring ensemble ecological niche modeling. Trop Med Infect Dis. 2022;8(1):24.
27. Gong YF, Li YL, Zhang LJ, Lv S, Xu J, Li S. The potential distribution prediction of *Oncomelania hupensis* based on newly emerging and reemergent habitats—China, 2015–2019. China CDC Wkly. 2021;3(5):90–3.
28. Tu YH, Hong XL, Zeng AG, Hu ZH, Ge J, Chen HG, et al. Observation on comprehensive control strategy for schistosomiasis with emphasis on infectious source control in Poyang lake areas from. Chin J Schisto Control. 2015;27(3):311–20 (in Chinese).
29. Yang GJ, Zhou XN, Sun LP, Wu F, Zhong B, Qiu DC, et al. Compensatory density feedback of *Oncomelania hupensis* populations in two different environmental settings in China. Parasit Vectors. 2011;4:133.
30. Gong Q, Janowski M, Luo M, Wei H, Chen B, Yang G, et al. Efficacy and adverse effects of atropine in childhood myopia: a meta-analysis. JAMA Ophthalmol. 2017;135(6):624–30.
31. Li HT, Zhou YB, Liu JM. The impact of cesarean section on offspring overweight and obesity: a systematic review and meta-analysis. Int J Obes (Lond). 2013;37(7):893–9.
32. Tan E, Braithwaite I, McKinlay CJD, Dalziel SR. Comparison of acetaminophen (paracetamol) with ibuprofen for treatment of fever or pain in children younger than 2 years: a systematic review and meta-analysis. JAMA Netw Open. 2020;3(10): e2022398.
33. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for Joinpoint regression with applications to cancer rates. Stat Med. 2000;19(3):335–51.
34. Clegg LX, Hankey BF, Tiwari R, Feuer EJ, Edwards BK. Estimating average annual per cent change in trend analysis. Stat Med. 2009;28: 3670e82.
35. Gu K, Zhou Y, Sun H, Dong F, Zhao L. Spatial distribution and determinants of PM2.5 in China's cities: fresh evidence from IDW and GWR. Environ Monit Assess. 2020;193(1):15.
36. Yang W, Zhao Y, Wang D, Wu H, Lin A, He L. Using principal components analysis and IDW interpolation to determine spatial and temporal changes of surface water quality of Xin'anjiang River in Huangshan, China. Int J Environ Res Public Health. 2020;17(8):2942.
37. Zhang GM, Ma SC, Cao ZG, Wang Y, Zhang SQ, Wang TP, et al. Water level changes caused from the Three Gorges Dam impact on the breeding and distribution of *Oncomelania* snails in the marshland of Chenqiaozhou, Hexian County, Anhui Province. Chin J Dis Control Prev. 2018;22(9):943–7 (In Chinese).

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38. Zhu CF, Zeng QF, Li YY, Lv SB, Huang WJ. Variation of *Oncomelania* and schistosomiasis in midstream area of Yangtze River after operation of Three Gorges Reservoir. Yangtze River. 2015;3:74–6 (in Chinese).

39. Wu XH, Zhang SQ, Xu XJ, Huang YX, Steinmann P, Utzinger J, et al. Effect of floods on the transmission of schistosomiasis in the Yangtze River valley, People's Republic of China. Parasitol Int. 2008;57(3):271–6.

40. Gray DJ, Thrift AP, Williams GM, Zheng F, Li YS, Guo J, et al. Five-year longitudinal assessment of the downstream impact on schistosomiasis transmission following closure of the Three Gorges Dam. PLoS Negl Trop Dis. 2012;6(4): e1588.

41. Hu Y, Li R, Bergquist R, Lynn H, Gao F, Wang Q, et al. Spatio-temporal transmission and environmental determinants of schistosomiasis japonica in Anhui Province, China. PLoS Negl Trop Dis. 2015;9: e3470.

42. Zheng J, Gu XG, Xu YL, Ge JH, Yang XX, He CH, et al. Relationship between the transmission of schistosomiasis japonica and the construction of the Three Gorge Reservoir. Acta Trop. 2002;82(2):147–56.

43. 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(7):973–9.

44. Seto EYW, Wu WP, Liu HY, Chen HG, Hubbard A, Holt A, et al. Impact of changing water levels and weather on *Oncomelania hupensis* populations, the snail host of *Schistosoma japonicum*, downstream of the Three Gorges Dam. EcoHealth. 2008;5:149–58.

45. Hu F, Li QY, Dai XF, Li ZJ, Lv SB, Lu CF, et al. Impact of continuous low water stage on the breeding environment of *Oncomelania hupensis*: a case study of Poyang lake area in China. Infect Dis Poverty. 2020;9(1):103.

46. Zhu HM, Xiang S, Yang K, Wu XH, Zhou XN. Three gorges dam and its impact on the potential transmission of schistosomiasis in regions along the Yangtze river. EcoHealth. 2008;5:137–48.

47. McManus DP, Gray DJ, Li Y, Feng Z, Williams GM, Stewart D, et al. Schistosomiasis in the People's Republic of China: the era of the Three Gorges Dam. Clin Microbiol Rev. 2010;23(2):442–66.

48. Li F, Ma S, Li Y, Tan H, Hou X, Ren G, et al. Impact of the Three Gorges project on ecological environment changes and snail distribution in Dongting Lake area. PLoS Negl Trop Dis. 2017;11(7): e0005661.

49. Li W, Hang DR, You BR, Chen XJ, Chen XJ, Yang K, et al. Effect of environmental change in marshland after implementation of Three Gorges reservoir project on schistosomiasis in Jiangsu Province. Chin J Schisto Control. 2013;25(06):576–80 (In Chinese).

50. Huang YX, Sun LP, Hong QB, Gao Y, Zhang LH, Gao Y, et al. Longitudinal observation on fluctuation trend of distribution and spread of *Oncomelania* snails after floodwater in marshland of lower reaches of Yangtze River. Chin J Schisto Control. 2004;16(04):253–6 (In Chinese).

51. 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(8):837–9.

52. Liu MM, Feng Y, Yang K. Impact of micro-environmental factors on survival, reproduction and distribution of *Oncomelania hupensis* snails. Infect Dis Poverty. 2021;10(1):47.

53. Hong XC, Chen X, Jian XX, Wei FH, Zhu HG, Shao J, et al. Study of correlations between environment and the density of *Oncomelania hupensis* in lake regions with generalized additive model. Mod Prev Med. 2014;41:3265–7 (In Chinese).

54. Zheng Y, Shi Y, Li S, Deng W, Zhou J, Hu B, et al. Environmental determinants for snail density in Dongting lake region: an ecological study incorporating spatial regression. Am J Trop Med Hyg. 2022;107(6):1178–84.

55. Yang Y, Gao J, Cheng W, Pan X, Yang Y, Chen Y, et al. Three Gorges Dam: polynomial regression modeling of water level and the density of schistosome-transmitting snails *Oncomelania hupensis*. Parasit Vectors. 2018;11(1):183.

56. Lv D, Jiang Q, Wang T. Research progress on the effects of drowning on the survival and reproduction of *Oncomelania hupensis*. Chin J Parasit Dis Control. 2004;17:61–2 (In Chinese).

57. Zheng YJ, Zhong JH, Xu XL, Lin DD, Zhao GM, Zhang SJ, et al. Influence of drowning on survival of *Oncomelania*. Chin J Schisto Control. 2002;14:46–9 (In Chinese).

58. Guo SY, Li L, Zhang LJ, Li YL, Li SZ, Xu J. From the one health perspective: *Schistosomiasis japonica* and flooding. Pathogens. 2021;10(12):1538.

59. Mutuku FM, King CH, Bustinduy AL, Mungai PL, Muchiri EM, Kitron U. Impact of drought on the spatial pattern of transmission of *Schistosoma haematobium* in coastal Kenya. Am J Trop Med Hyg. 2011;85(6):1065–70.

60. Jiang JM, He YP, Fei SM, Huang LL, Chen XM, Zhang XD, et al. Relationships between the quantity of *Oncomelania* and environmental factors of vegetation and soil in hilly and mountainous areas. Wetland Sci Manag. 2006;2(4):33–9 (in Chinese).

61. Zhu HR, Liu L, Zhou XN, Yang GJ. Ecological model to predict potential habitats of *Oncomelania hupensis*, the intermediate host of *Schistosoma japonicum* in the mountainous regions, China. PLoS Negl Trop Dis. 2015;9(8): e0004028.

62. Zhou YB, Chen Y, Liang S, Song XX, Chen GX, He Z, et al. Multi-host model and threshold of intermediate host *Oncomelania* snail density for eliminating schistosomiasis transmission in China. Sci Rep. 2016;6:31089.

63. Gray DJ, Williams GM, Li Y, McManus DP. Transmission dynamics of *Schistosoma japonicum* in the lakes and marshlands of China. PLoS ONE. 2008;3(12): e4058.

64. Zhang ZJ, Carpenter TE, Lynn HS, Chen Y, Bivand R, Clark AB, et al. Location of active transmission sites of *Schistosoma japonicum* in lake and marshland regions in China. Parasitology. 2009;136(7):737–46.

65. Sun LP, Wang W, Zuo YP, Zhang ZQ, Hong QB, Yang GJ, et al. An integrated environmental improvement of marshlands: impact on control and elimination of schistosomiasis in marshland regions along the Yangtze River, China. Infect Dis Poverty. 2017;6(1):72.

66. Yang K, Wang XH, Yang GJ, Wu XH, Qi YL, Li HJ, et al. An integrated approach to identify distribution of *Oncomelania hupensis*, the intermediate host of *Schistosoma japonicum*, in a mountainous region in China. Int J Parasitol. 2008;38(8–9):1007–16.

67. Liu Y, Zhong B, Wu ZS, Liang S, Qiu DC, Ma X. Interruption of schistosomiasis transmission in mountainous and hilly regions with an integrated strategy: a longitudinal case study in Sichuan, China. Infect Dis Poverty. 2017;6(1):79.

68. Gong YF, Hu XK, Hao YW, Luo ZW, Feng JX, Xue JB, et al. Projecting the proliferation risk of *Oncomelania hupensis* in China driven by SSPs: a multi-scenario comparison and integrated modeling study. Adv Clim Change Res. 2022;13(2):258–65.

69. Ohmae H, Iwanaga Y, Nara T, Matsuda H, Yasuraoka K. Biological characteristics and control of intermediate snail host of *Schistosoma japonicum*. Parasitol Int. 2003;52(4):409–17.